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Digital Factory for Human-oriented Production Systems

The Integration of International Research Projects

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Preface

The idea of a book about Digital Factory (DiFac) was born in May 2008 during the technical meeting in Seoul, Korea. This book represents more than three years of collaboration among partners from different corners of the world. It provides new concepts, frameworks and lessons learned targeting the future Digital Factory, which should integrate novel technologies, processes and humans to tackle the everyday challenges of the business environment.

DiFac is a common acronym for three research projects: one in Europe, the other in Korea and the third in Switzerland. Each one of them deals with the concept of the Digital Factory under different nuances. The Digital Factory is a paradigm dealing with the use of new technologies during the entire product lifecycle, 3D simulation for facility management and ergonomics, decision-making system, radio frequency identification (RFID), enterprise resource planning (ERP), knowledge-based management tool, virtual and augmented reality, and semantic web are only some of the topics with which DiFac deals.

The three theoretical sections of this book are not referred to the regions of the International Manufacturing Systems (IMS) project, but to more general topics organized in a coherent path. From its foundations, the three projects integrated under the DiFac umbrella looked forward to providing new tools and technologies for both big and small companies to enable them to be more competitive. Nevertheless, DiFac and its related deliverables presented in this book do not only represent the answer to technological challenges, but also define a new way of working by enabling workers to be more productive and empowering them to make better decisions thanks to the availability of information and knowledge, which in traditional environments is in most cases not available.

Information management, knowledge management, automation, ergonomics, production planning, RFID and factory simulation etc. are some of the key subjects embedded in this book that still represent a challenge for many manufacturing companies around the globe. Therefore, we as editors, on behalf of the complete DiFac project consortium, have integrated the different outcomes of this international project to provide the main trends, frameworks, models and potential solutions to practitioners and at the same time highlight the lessons learned providing an insight of the opportunities to still develop in future collaborative research projects. As a result, this book provides a section of case studies, which evidence the work done by academic partners in collaboration with the industrial partners to test, improve and further develop the different prototypes created during the project.

We take the opportunity to thank the South Korean Ministry of Knowledge Economy, the European Commission under the Framework Program 6 (FP6) and the Swiss Commission for Technology and Innovation (CTI) for funding the three projects in the different regions. We also express our gratitude to all our academic and industrial partners who contributed with their hard work to be able to develop the promised prototypes and share their findings in this book. Last but not least, we would like to sincerely thank Prof. Joung Hwan Mun from Sungkyunkwan University (SKKU, Korea) and Prof. Claudio R. Boër from Intelligent Manufacturing Systems (IMS) and University of Applied Sciences of Southern Switzerland (SUPSI) for proposing, facilitating, guiding, energizing and engaging the partners from the different corners of the world to make this project a reality.

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Introduction

This book describes how implementing various facets of the Digital Factory is possible to improve a series of processes, directly related to manufacturing activities or dealing with more general company organisational aspects. This is done in order to create a new generation of human-oriented production systems, where the "knowledge workers" can use specifically developed tools that enhance their safety and well-being while improving company effectiveness and efficiency. The methodologies and tools of the Digital Factory will also deal with new challenges related to the simultaneous shortening of time to market, shrinking of margins and increase in product differentiation. This implies the necessity to enhance new product development process and the consequent adaptation of production systems, processes and management policies. Three research projects enabled strong collaboration among 18 international partners with highly complementary competences, which resulted in an integrated multidisciplinary approach that provides the pillars of the Digital Factory.

The enhancement of the collaboration level is one of the key advantages obtained through the application of the Digital Factory concepts. On the one hand, this is obtained thanks to the development of tools allowing the elicitation, management and sharing of explicit and implicit knowledge as well as competence improvements, based on best practices identification, formalisation and dissemination. On the other hand, software tools for supporting some complex tasks have been developed in order to also facilitate their undertaking by distributed teams belonging to different supply chain actors and working collaboratively. For instance, one of the main objectives of FP7 DiFac is the development of an innovative Collaborative Manufacturing Environment (CME) for next generation digital manufacturing. The DiFac CME will be used as a framework to support group work in an immersive and interactive way, for concurrent product design, prototyping and manufacturing, as well as worker training. It will provide support for data analysis, visualization, advanced interaction and presence within the virtual environment, ergonomics analysis and collaborative decision-making. Within the DiFac CME, a systematic representation of product and process knowledge in a mixed 3D collaborative manufacturing environment will be provided to the user.

A distinctive point of the developed CME is to complement the common collaboration technologies for distributed design and manufacturing, based on networked collaborative decision-making and project management, with Virtual Reality (VR) and Augmented Reality (AR) technologies in order to lead to remarkable breakthroughs in enhancing manufacturing collaboration, from the development of digital mock-ups and virtual prototypes, to production simulation, maintenance and training.

The application of this innovative CME is oriented to the improvement of workforce safety and well-being, which are taken into account from product development to factory layout and processes design and evaluation. This is due to the integration of the VR/AR software tools with digital human models and software tools that incorporate ergonomic analysis into working conditions of the digital factory. These software tools will come in the form of a photorealistic digital human that moves and poses as a real person would, interacting with a industrial environment and ultimately providing feedback concerning, among other things fatigue, reach envelopes, discomfort, muscle and joint stress and energy expenditure. Two different task-based methods for Digital Human Modelling (DHM) simulation have been developed to simplify the motion generation procedure and inverse dynamic modelling as well as to analyse human motion more accurately. The proposed DHM aims at solving some shortcomings of the solutions currently available on the market because the motion generation procedure becomes less time consuming while still providing good accuracy even for the analysis of complex human tasks in dynamic working conditions. Workers safety and well-being are also enhanced thanks to the availability of reliable and updated information and best practices as well as their provision with innovative tools, such as AG training materials for maintenance and other activities.

The tools developed in the framework of DiFac have to be strongly integrated to each other, in order to fully deploy their benefits, but also have to complement the functionalities already offered by the legacy company information system ensuring a seamless adoption. For these reasons, a great attention has been devoted for ensuring a correct information formalisation and sharing. The PPR^{+H} (Product, Process, Resource and Human) Schema developed using XML and the PPR^{+H} Integrator constitutes the backbone of this information exchange ensuring neutral formalisms, compliant with the currently used standards and facilitating the communication with Product Data Management (PDM) and Enterprise Resource Planning (ERP) systems. In fact, many Digital Factory tools require input from and/or provide output that can be directly used by the legacy information system. For instance, production system discrete event simulation models can be filled with parameters stemming from the PDM/ERP systems, the same applies for some data concerning manufacturing processes required by the Digital Human Modelling for estimating fatigue. On the other hand, the RFID–ERP interfacing scheme provides a multitude of transactional data to the ERP system at a higher frequency and with an enhanced reliability. Other DiFac tools, such as the Factory

Constructor, can allow to adjust the parameters contained in the PDM/ERP systems in order to improve the characteristics of the production systems.

In a Digital Factory implicit knowledge also has to be carefully managed and shared. Furthermore, the “knowledge workers” should be stimulated to dynamically provide feedbacks and input in order to efficiently apply Business Process Management (BPM) practices. The Intelligent Web, being a synergic combination of Web 2.0 and 3.0 concepts and tools, is proposed as a suitable tool for collaborative and dynamic creation and sharing of knowledge, by means the owners’ interaction and co-authoring where knowledge is systematically created and reused.

The creation of a Digital Factory, for achieving human-oriented production system, implies integrating ergonomics concepts in as many tools as possible, as well as to ensure a high usability of these tools. Presence and flow are two performance measures extremely important while evaluating the quality of VR and AR software tools and these can also be successfully applied to less interactive tools, such as the Intelligent Web framework proposed for managing information creation and sharing.

Collaboration, ergonomics and presence are considered among the foundations of the Digital Factory and are treated in the first part of this book.

The second part of this book is dedicated to the tools developed for enhancing knowledge acquisition, modelling and sharing. The PPR^{+H} Hub, which provides the reference data models allowing data interchanges among the various tools is, introduced in Chap. 4. In order to complement the rich description of physical process provided by the PPR^{+H} Hub and better covering business processes and implicit knowledge, an Intelligent Web tool, is developed and described in Chap. 9. In parallel the importance of BPM practices for building the knowledge-based Digital Factory is highlighted in Chap. 7. The remaining chapters of this part deal with transactional data and production system parameters exchange. Chapter 5 describes the potential applications of RFID and potential strategies according to the organisation and supply chain typology. Chapter 6 tackles the same problematic, adopting a more technology-oriented approach, focusing on the integration of the RFID infrastructure with the legacy ERP and proposing a versatile interfacing scheme. Finally, Chap. 8 concentrates on closed loop information system applications, especially those devoted to enhance the communication among ERP system and workshops.

Applying the Digital Factory concept can require significant modifications to the current production system and supply chain structure. A series of tools developed to support the design of the human-oriented production system are described in Part III. First of all, the Digital Human Modelling, allowing to integrating physical body constraints into the redesign of production systems, is presented in Chap. 10. Chapter 11 describes a bundle of VR tools for process planning and optimisation. Factory design is supported by the GIOVE Virtual Factory immersive viewer presented in Chap. 12. The performance of the various configurations proposed using the VR tools can then be easily tested using a web-based discrete event simulation (Chap. 14). The rich 3D representations of machines and layout are also used for more operational objectives, such as training. For instance, an AR application for remote maintenance is described in Chap. 13.

The industry-led vocation of the Intelligent Manufacturing Systems (IMS) program as well as the involvement of various companies in all the three research projects result in some applications already deployed. A series of industrial case studies are thus presented in Part IV to underline the potential benefits of the developed tools and methodologies and to better delimitate some application contexts.

Luca Canetta
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Marco Sacco

Contents

DiFac: Three Projects and an International Cooperation with IMS Framework

IMS, the Intelligent Manufacturing System program was born 20 years ago from an idea of Prof. Yoshikawa. Manufacturing, he was saying, should not be only competitive if we want to change the world and make it more sustainable. Manufacturing is contributing to the wealth and development of the world in great and many ways but it contributes also to its pollution more than any other human activities. A country alone cannot deal with this problem and that is when the IMS idea was born.

It took some time in order to agree on a term of reference for cooperation but then projects started to roll in from all regions (Japan, Korea, European Union, United States, Canada, Australia and Switzerland). All technologies were researched, integrated and tested. The IMS program is supported and coordinated by government but is lead by industry and therefore the results reached the heart of the manufacturing system and in many cases also the market. Because the program is precompetitive, companies could share important results and reach agreement about the standards.

Information technology applications were developed considerably in IMS projects as well as environmentally friendly technologies. But sustainability needs three 'E's: Ecology, Economy and Equity (social) to be really effective, and the DiFac project touches deeply in the social aspect looking at the implementation of information technology but respecting the human side of the factory.

IMS is now launching a new program called MTP, the Manufacturing Technology Platforms, that is looking at cooperation among manufacturing actors in more innovative way bringing together projects already ongoing around the world. The MTP program focuses on five main areas: sustainable manufacturing, energy efficiency manufacturing, key technologies, standards and education. The MTP program is very interesting for industry and academia, and it has seen a huge success in a just over a year of existence. DiFac will certainly contribute in one of the MTP initiatives already ongoing or in preparation.

DiFac Advantages in the International Collaboration

IMS DiFac—The DiFac project (Title: Digital Factory for human-oriented production system) was designed to develop digital factory for human-oriented production systems to consider the industrial safety factors from the initial stage of the development of the digital factory, because the industrial safety problem has been embossed dramatically in the international society.

For this purpose, it has been performed by different regional projects from Korea, EU and Switzerland regions with different focuses. Each regional project divides into four technical fields of production, process, resource and human information management and integration; human modelling ergonomics collaborative VR environment and digital factory management with ERP.

The developed technologies from each regional project will be shared to upgrade the existing solutions and reinforce the international R&D relationship. Therefore, there are added values derived from the international collaboration as follows:

- Sharing the technologies of human modelling and quantitative analysis of industrial safety
- Simulate and evaluate human postures and motions without any manual manipulation tasks
- Ergonomic and biomechanical analysis of human motions
- For simulating and evaluating the industrial working environments
- For evaluating work strategy considering human factors
- Sharing the technologies of VR
- A collaborative strategy for digital factory activities considering group presence and ergonomics
- Evaluate the virtualized collaborative manufacturing environment
- For collaborative product prototyping
- For constructing, simulating and evaluating the virtual digital factory
- For training, maintenance and commissioning
- Sharing the technologies of ERP system
- Implement an integrated company-wide information management system
- A new ERP–human interface for shop-floor information feedback
- For designing and validating an ERP–simulation interface to optimize the production process
- Exploration of the RFID technology integration with the ERP
- A new governance model to facilitate the implementation of new ERP functionalities in companies

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Part I
Presence, Collaboration and Ergonomics: Foundations of the Digital Factory

Chapter 1
Flow for Presence Questionnaire

Claudia Redaelli and Giuseppe Riva

Abstract This chapter discusses the development of a new questionnaire for measuring Presence and Flow state of the users of technological devices. The human factors are the fundamentals of the EC-funded project DiFac and the Presence measurement is one of those. Presence is the sense to be immerses in a synthetic environment any nature it has. The questionnaire is an innovative instrument to detect the level of Presence sensation and the quality of the experience whenever it approaches the Optimal state. This chapter presents the methodology and the possible approach of the Flow for Presence questionnaire in an industrial environment explaining how this methodology can evaluate the well-being of humans in the factory. The application on the Factory Constructor underlines the industrial benefits of this project result.

1.1 Introduction

The industrial world is managed in a precise way by using measurable factors and indicators. An enterprise looks for precise markers as numbers indicate, for example, the production rate or the increasing factor for coping with market needs or others exact ratings. This chapter presents the definition of Presence, one of the human factors base of the European DiFac project and its application in industrial field. Being Presence a psychological concept, there are various definitions of this concept and no one is better than the others, but all of them are good depending of the point of analysis. During the project, a questionnaire was developed for

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measuring the Presence level of a virtual environment (VE) and in addition the Flow state. *Flow* is a subjective state that people report when they are completely involved in something to the point of forgetting time, fatigue, and everything else but the activity itself.

The questionnaire itself is an innovative step forward in the Presence measurement linked with Flow, and this chapter shows how the results could be immediately useful for people who do not have specific knowledge in psychological fields.

The text finally presents an application with the VE called Factory Constructor (FC) one of the results from European DiFac presented in details in Chap. 10 of this book.

1.2 Presence

1.2.1 Presence: A First Definition

The term "*Presence*" entered the general scientific debate in 1992 when Sheridan and Furness used it in the title of a new journal dedicated to the study of virtual reality (VR) systems and teleoperations: *Presence, Teleoperators and Virtual Environments.* In the first issue, Sheridan clearly refers to Presence as an experience elicited by technology use (Sheridan 1992, pp 123–124): the effect felt when controlling real-world objects remotely as well as the effect people feel when they interact with and immerse themselves in VEs.

A first definition of "Presence" is introduced by the International Society of Presence Research (ISPR). ISPR researchers define "Presence" (a shortened version of the term "telePresence") as:

> A psychological state in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience. (International Society for Presence Research 2000)

Nevertheless, the above definition has two limitations. First, what is Presence for? Why do we experience Presence? As underlined by Lee (2004):

> Presence scholars, may find it surprising and even disturbing that there have been limited attempts to explain the fundamental reason why human beings can feel Presence when they use media and/or simulation technologies. (p 496)

Second, is Presence related to media only? As commented by Biocca (1997) and agreed by most researchers in the area:

> While the design of virtual reality technology has brought the theoretical issue of Presence to the fore, few theorists argue that the experience of Presence suddenly emerged with the arrival of virtual reality. (http://jcmc.indiana.edu/vol3/issue2/biocca2.html)

Recent insights from cognitive sciences suggest that Presence is a neuropsychological process that results in a sense of agency and control (Riva 2006, 2007; Riva et al. 2008). For instance, Slater suggested that Presence is a selection mechanism that organizes the stream of sensory data into an environmental gestalt or perceptual hypothesis about current environment (Sanchez-Vives and Slater 2005; Slater 2002).

Within this framework, supported by ecological/ethnographic studies (Gamberini and Spagnolli 2003; Gibson 1979; Mantovani and Riva 1999, 2001; Riva et al. 2004; Spagnolli and Gamberini 2005; Spagnolli et al. 2003; Waterworth and Waterworth 2006), any technology, virtual or real, does not provide undifferentiated information or ready-made objects in the same way for everyone. It offers different opportunities and creates different levels of Presence according to its ability in supporting the users' intentions.

1.2.2 Presence: A Second Definition

Recent findings in cognitive science suggest that Presence is a neuropsychological phenomenon, evolved from the interplay of our biological and cultural inheritance, whose goal is the enaction of volition: Presence is the *perception of successfully transforming intentions into action (enaction).*

Recent research by Haggard and Clark (Haggard and Clark 2003; Haggard et al. 2002) on voluntary and involuntary movements provides direct support for the existence of a specific cognitive process–binding intentions with actions. In their words:

> Taken as a whole, these results suggest that the brain contains a specific cognitive module that binds intentional actions to their effects to construct a coherent conscious experience of our own agency. (Haggard et al. 2002, p 385)

Varela et al. (1991) define "*enaction*" in terms of two intertwined and reciprocal factors: First, the historical transformations that generate emergent regularities in the actor's embodiment; second, the influence of an actor's embodiment in determining the trajectory of behaviors. As suggested by Whitaker (1995), these two aspects reflect two different usages of the English verb "enact." On one hand is "to enact" in the sense of "to specify, to legislate, to bring forth something new and determining of the future," as in a government enacting a new law. On the other hand is "to enact" in the sense of "to portray, to bring forth something already given and determinant of the present," as in a stage actor enacting a role. In line with these two meanings, Presence has a dual role:

- First, *Presence "locates" the self in an external physical and/or cultural space:* the Self is "present" in a space if he/she can act in it
- Second, *Presence provides feedback to the Self about the status of its activity*: the Self perceives the variations in Presence and tunes its activity accordingly.

First, we suggest that the ability to feel "present" in the interaction with a technology—an artifact—basically does not differ from the ability to feel "present" in our body. Within this view, "being present" during agency means that (1) the individual is able to successfully enact his/her intentions (2) the individual is able to locate himself/herself in the physical and cultural space in which the action occurs. When the subject is present during a mediated action (that is, an action supported by a tool), he/she incorporates the tool in his/her peripersonal space, extending the action potential of the body into virtual space (Clark 2003). In other words, through the successful enaction of the actor's intentions using the tool, the subject becomes "present" in the tool.

The process of Presence can be described as a sophisticated but covert form of monitoring action and experience, transparent to the self but critical for its existence. The result of this process is a sense of agency: The feeling of being both the author and the owner of one's own actions. The more intense the feeling of Presence, the higher the quality of experience perceived during the action (Zahoric and Jenison 1998). However, the agent directly perceives only *the variations* in the level of Presence: *breakdowns* and *optimal experiences* (Riva 2006).

Why do we monitor the level of Presence? The hypothesis on which the questionnaire is created is that this high-level process has evolved to control the quality of action and behaviors.

According to Csikszentmihalyi (1975, 1990), individuals preferentially engage in opportunities for action associated with a positive, complex, and rewarding state of consciousness, defined by him as "optimal experience" or "Flow." The key feature of this experience is the perceived balance between great environmental opportunities for action (challenges) and adequate personal resources in facing them (skills). Additional characteristics are deep concentration, clear rules and unambiguous feedback from the task at hand, loss of self-consciousness, control of one's actions and environment, positive effect, and intrinsic motivation. Displays of optimal experience can be associated with various daily activities, provided that individuals perceive them as complex opportunities for action and involvement (the concept is further explained in the following dedicated paragraph). An example of Flow is the case where a professional athlete is playing exceptionally well (positive emotion) and achieves a state of mind where nothing else is important to but the game (high level of Presence). From the phenomenological viewpoint, both Presence and Flow are described as absorbing states, characterized by a merging of action and awareness, loss of self-consciousness, a feeling of being transported into another reality, and an altered perception of time. Furthermore, both Presence and optimal experience are associated with high involvement, focused attention, and high concentration on the ongoing activity.

1.2.3 The Presence Levels

How can we achieve a high level of Presence during interaction with a technology? The answer to this question requires a better understanding of what intentions are.

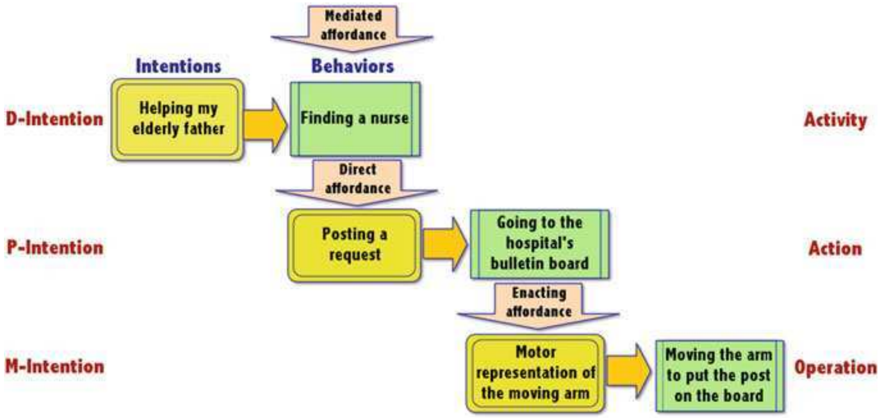

Fig. 1.1 The intentional cascade

According to folk psychology (Folk psychology is interpreted as a theory when the "common sense" perceptions of one's daily life, such as those of pain, pleasure, excitement, anxiety, etc., are interpreted as principles used to explain mental states), the intention of an agent performing an action is his/her specific purpose in doing so. However, the latest cognitive studies clearly show that any action is the result of a complex intentional chain that cannot be analysed at a single level (Pacherie 2006, 2008; Searle 1983).

Pacherie (2006, 2008) identifies three different "levels" or "forms" of intentions, characterized by different roles and contents: distal intentions (D-intentions), proximal intentions (P-intentions), and motor intentions (M-intentions):

- *D-intentions (future-directed intentions)*: These high-level intentions act as both intrapersonal and interpersonal coordinators and as prompters of practical reasoning about means and plans: "Helping my elderly father" is a D-intention, the object that drives the activity "finding a nurse" of the subject (see Fig. 1.1).
- *P-intentions(present-directed intentions)*: These intentions are responsible for high-level (conscious) forms of guidance and monitoring. They have to ensure that the imagined actions become current through situational control of their unfolding: "Posting a request for a nurse" is a P-intention driving the action "going to the hospital's bulletin board (see Fig. 1.1).
- *M-intentions (motor intentions)*: These intentions are responsible for low-level (covert) forms of guidance and monitoring: We may not be aware of them and have only partial access to their content. Furthermore, their contents are not propositional: In the operation "putting the post on the board" (see Fig. 1.1), the motor representations required to move the arm are M-intentions.

Any intentional level has its own role: *The rational (D-intentions), situational (P-intention) and motor (M-intention) guidance and control of action.* They form an intentional cascade (Pacherie 2006, 2008) in which *higher intentions generate lower intentions.*

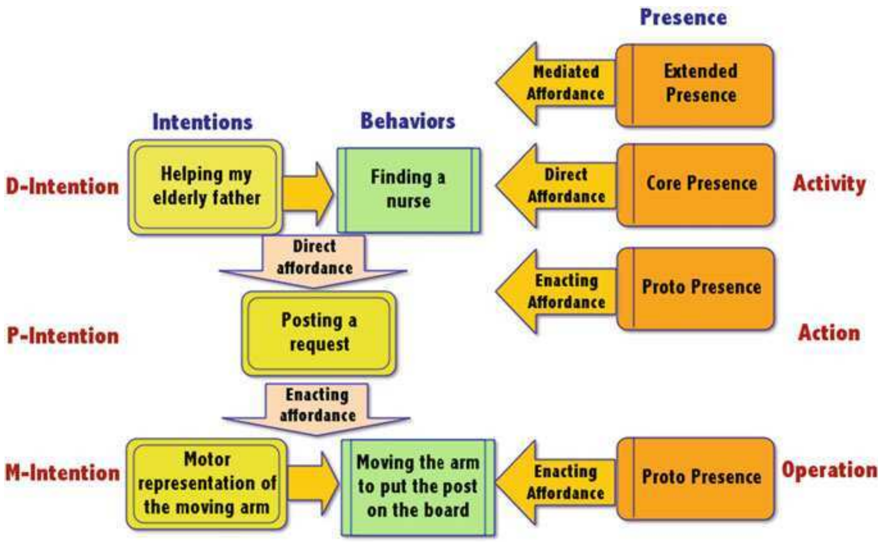

Fig. 1.2 Activity and Presence

We previously defined Presence as *the perception of successfully transforming intentions into action (enaction)*. However, even if we experience a single feeling of Presence during the enaction of our intentions, the three-level structure of the intentional cascade suggests that Presence, on the process side, can be divided into three different layers or sub-processes (for a broader and more in-depth description, see Riva 2008; Riva et al. 2004), described in Fig. 1.2:

- *Extended presence(D-intentions/activities)*: The role of "Extended Presence" is to *verify the relevance to the Self of possible/future events in the external world (Self vs. possible/future external world)*. The more the Self is able to identify mediated affordances (that cannot be enacted directly) in the external world, the higher the level of extended Presence will be.
- *Core presence (P-intentions/actions)*: This can be described as *the activity of selective attention made by the Self on perceptions (Self vs. present external world)*. The more the Self is able to identify direct affordances (that can be enacted directly with a movement of the body) in the external world, the higher the level of core Presence will be.
- *Proto presence (M-intentions/operations)*: This is the process of internal/external separation *related to the level of perception–action coupling (Self vs. non-Self)*. The more the Self is able to use the body for enacting direct affordances in the external world, the higher the level of proto Presence will be.

As underlined by Dillon et al. (2003), converging lines of evidence from diverse perspectives and methodologies support this three-layered view of Presence. In their analysis, they identify three dimensions common to all the different perspectives, relating to a "spatial" dimension (M-intentions), a dimension relating to how consistent the media experience is with the real world, "naturalness" (P-intentions), and an "engagement" dimension (D-intentions).

The role of the different layers will be related to the complexity of the activity done: The more complex the activity, the more layers will be needed to produce a high level of Presence (Fig. 1.2).

At the lower level, operations, proto Presence is enough to induce a satisfying feeling of Presence. At the higher level, activity, the media experience has to support all three layers.

As suggested by Juarrero (1999), high-level intentions (future intentions/objects) channel future deliberation by narrowing the scope of alternatives to be subsequently considered (cognitive reparsing). In practice, once the subject forms an intention, not every logical or physically possible alternative remains open. Once I decide to do "A," "non-A" is no longer an alternative and I will consider "non-A" as a breakdown (Bratman 1992).

1.2.4 Presence Measurements

Sheridan (1996) presents the concept of Presence as "natural (expected) responses of human and environment to each other." This concept merges into the idea of assessing physical responses by movement or sound into a measure of presence, for example, would the human react to a loud noise or swift movement in a VE as they would in the real world? The measure of reflexive responses as an indicator of presence is studying the response of the subject in comparison with a real-life reflex response, for example, avoiding an object which is coming towards the face (explored in Nichols et al. 2000). It has been suggested that this indicates a feeling of presence as the participant reacts to the situation as he or she would in the real world suggesting he or she feels to some extent that he or she is "there" in the virtual world.

Barfield and Weghorst and Billinghurst (1993) acknowledged the need for a set of metrics that can be used to measure performance within VEs and to quantify the level of presence experience by participants of virtual worlds. They suggested as potential indicators of presence virtual world task performance, subjective assessment and degree of disorientation to be considered conclusive. Within this chapter, it is noted that subjective rating of Presence is not entirely dependable but is used in lieu of a suitable and more reliable alternative because it provides a good initial indicator for initial exploration. Alternative "more robust" metrics that are being developed and researched are commented on, for example, physiological indicators, such as posture, muscle tension, and cardiovascular responses to virtual events, such as heart rate evoked by looming of virtual objects. It was also noted that speed and accuracy on tasks performed solely within the VE might also be influenced by the sense of virtual presence. The possibility of using a secondary task method for measuring Presence similar to that used to measure mental workload is considered, where the quality of performance of the secondary task is an indication of the Presence experienced by the subject (i.e., poor performance indicates high Presence as resources are concentrated on the environment not the secondary task).

Bystrom et al. (1999) present the Immersion, Presence, Performance model for the measurement of Presence. It provides a guide determining the factors that influence Presence, aid research into the relationship between immersion, presence, and performance in VEs, and help designers of virtual worlds select appropriate display features when they design VEs. *Immersion* in this case is defined as: The quantifiable aspect of display technology, primarily determined by the extent to which displays are

- Inclusive, stimuli from the real world is excluded from the user
- Extensive, the number of sensory modalities accommodated by the system
- Surrounding, how panoramic the displays are, and
- Vivid, the resolution of the displays

Slater and Wilbur (1995) argue that a sense of presence in a VE will contribute to user behavior that closer matches real-world behavior, such as reflex responses to suitable stimuli. For example, when an object looming towards the user's head and he or she moves his or her head avoiding obstacles even though intellectually he or she knows the object do not actually exist.

Freeman (1999) assesses Presence by using a hand-held slider, and participants were asked to continually rate their feelings of Presence with continually changing display stimulus.

In Kalawsky et al. (1999), it is suggested that the evaluation of Presence involves the following measures:

- *Objective measures*: task demands, task results, correlated measures (e.g., error numbers, achieved task levels, etc.)
- *Subjective measures*: on-line evaluations, post-test evaluation, questionnaires, explanation of high stress
- *Physiological measures*: heart rate, blood pressure, respiration rate, ECG
- Task performance evaluation
- Learning efficiency

Although a combination of all these measures may provide the most comprehensive measure of the concept of presence that can be achieved, realistically it is not possible to measure all these variables with respect to every system. Being one of the DiFac objectives to have a methodology easy to be used, the selected measurement was a questionnaire. The Flow for Presence Questionnaire (FPQ) is presented in the following paragraph.

1.3 Flow

Why do people perform time-consuming, difficult, and often dangerous activities for which they receive no discernible extrinsic rewards? This was the question that originally prompted Csikszentmihalyi and his companions into a program of research that involved extensive interviews with hundreds of rock climbers, chess players, athletes, and artists (Csikszentmihalyi 1975; Nakamura and Csikszentmihalyi 2002). The conclusion was that in all the studied groups, the interviewees reported a very similar subjective experience: They enjoyed it so much that they would like to repeat it further times. This was denominated the *flow experience*, because in describing their feelings when the activity was going well, several respondents used the metaphor of a current that carried them along effortlessly.

Flow is a subjective state that people report when they are completely involved in something to the point of forgetting time, fatigue, and everything else but the activity itself. It is what we feel when we read a fascinating novel or play a good game of your favorite sport or take part in a stimulating conversation. The defining feature of flow is intense experiential involvement in moment-to-moment activity. Attention is fully invested in the task at hand, and the person functions at his or her fullest capacity.

1.3.1 Flow Characteristics

The intense experiential involvement of flow is responsible for three subjective characteristics commonly reported:

The merging of action and awareness

During the flow state, the attention resources are fully invested in the task, so that objects beyond the immediate interaction generally fail to enter awareness.

One of these objects is the self. Respondents frequently describe a loss of self-consciousness during flow. Without the required attention resources, the usual dualism between actor and action disappears. As Mead (1934) proposed, the "me" disappears during flow, and the "I" takes over.

A sense of control

During flow, the typical experience is a great sense of control or, more precisely, a lack of anxiety about losing control. This sense of control is also reported in activities that involve serious risks, such as hang gliding, rock climbing, and race car driving. The described sense of control is in fact the possibility, rather than the actuality, of control.

Worrying about whether we can succeed at what we are doing (any activity we are performing) is one of the major sources of psychic entropy in everyday life, and its reduction during optimal experience is one of the reasons why the experience becomes enjoyable and rewarding.

An altered sense of time

During flow, attention is so fully invested in moment-to-moment activity that there is little left over to devote towards the mental processes that contribute to the experience of duration (Friedman 1990). As a result, persons deeply immersed in an activity typically report time passing quickly (Conti 2001).

1.3.2 Flow Measurement

Conventional Flow research has adopted two main methodologies: The flow questionnaire, which explains the concept and asks respondents to describe similar previous experiences, and the Experience-Sampling Method (Larson and Csikszentmihalyi 1983), which interrupts respondents at random time intervals.

The flow questionnaire (Csikszentmihalyi 1982; Delle Fave and Massimini 1988) contains three standard descriptions of Flow derived from Csikszentmihalyi's earlier research. The three quotations, which are also used in this research, are:

1. My mind isn't wandering. I am not thinking of something else. I am totally involved in what I am doing. My body feels good. I don't seem to hear anything. The world seems to be cut off from me. I am less aware of my problems and myself.
2. My concentration is like breathing. I never think of it. I am really oblivious to my surroundings after I really get going. I think that the phone could ring, and the doorbell could ring, or the house burn down or something like that. When I start, I really do shut out the whole world. Once I stop, I can let it back in again.
3. I am so involved in what I am doing, I don't see myself as separate from what I am doing.

In the Flow questionnaire, respondents were presented (in a self-completion questionnaire) with the three descriptions and asked whether they could recall similar experiences. They were then asked to describe these experiences and to rate associated feelings, e.g., level of involvement, effort, anxiety, etc. This methodology depends on respondents recognizing the flow descriptions and relating them to their own previous experiences.

1.4 How to Design Technologies that Foster Presence and Flow

This perspective allows us to predict under which mediated situations the feeling of Presence can be enhanced or reduced.

First, minimal Presence results from an almost complete lack of integration of the three layers discussed in paragraph 4.2.3, such as is the case when attention is mostly directed towards contents of extended consciousness that are unrelated to the present external environment (e.g., I'm in the office trying to write a letter but I'm thinking about how to find a nurse for my father). By the same reasoning, maximal Presence arises when proto Presence, core Presence, and extended

Presence are focused on the same external situation or activity (Waterworth and Waterworth 2006). Maximal Presence thus results from the combination of all three layers with a tight focus on the same content. The concepts described above are summarized by the following points:

1. *The lower the level of activity, the easier it is to induce maximal Presence*: The object of an activity is wider and less targeted than the goal of an action. So, its identification and support are more difficult for the designer of an advanced technology. Furthermore, the easiest level to support is the operation. In fact, its conditions are more "objective" and predictable, being related to the characteristics (constraints and affordances) of the artifact used: It is easier to automatically open a door in a VE than to help the user in finding the right path for the exit. At the lower level, operations, proto Presence is enough to induce a satisfying feeling of Presence. At the higher level, activity, the media experience has to support all the three levels.
2. *We have maximal Presence when the environment is able to support the full intentional chain of the user*: This can explain (i) the success of the Nintendo Wii over competing consoles (it is the only one to fully support M-intentions) and (ii) the need for a long-term goal to induce a high level of Presence after many experiences of the same rehabilitation technology.
3. *Subjects with different intentions will not experience the same level of Presence, even when using the same technology*: This means that understanding and supporting the intentions of the user will improve his/her Presence during the interaction with the technology.
4. *Action is more important than perception*: I'm more present in a perceptually poor VE (e.g., a textual MUD) where I can act in many different ways than in a real-like VE where I cannot do anything.

1.5 The FPQ

The FPQ is the Presence measurement tool developed in DiFac project. It is structured in three parts.

The *first part* contains three descriptions of the optimal experience. The subjects judge, with a Likert point scale (0–8), the VR ambient, verifying in which moment they "feel" an optimal experience, being in Flow condition.

The personal variables are explored focusing items on the following subjects:

- Cognitive
- Affective
- Motivation
- Skills and challenge

The *second part* of the questionnaire is created to obtain a general picture of the psychological individual selection in his or her daily optimal experience. The point

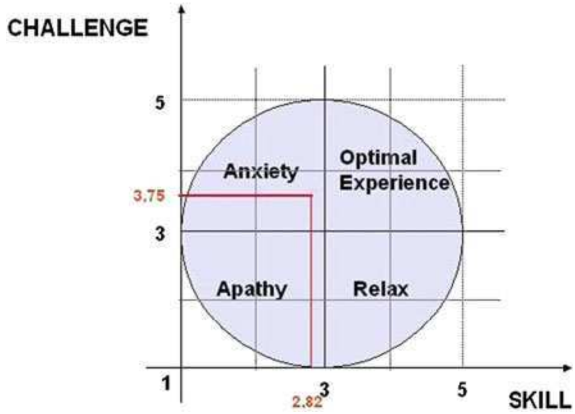

Fig. 1.3 Testers' state_skill and challenge balance

rating in the other experiences (daily life experience) is necessary because of the term of comparison to know the critical level that distinguishes a "normal" experience from an "optimal" one. In sum, each subject is a "himself control," there is no comparison with another subject.

The *third part* of FPQ has been taken from a version of the Flow Questionnaire in which an Italian research group measures the state called anti-flow (Massimini et al. 1987; Delle Fave and Massimini 1990, 1992). It is the antithetic or opposite condition with respect to the optimal experience. Investigating the anti-flow state is important to build a correct rating point in terms of measurement structural validity.

The questionnaire passed through three validation phases. The following paragraphs show the tests phased of the questionnaire. At the time the project was in its evaluation phase, the questionnaire was not definitive, it passed the first and second phases, and it was composed by 40 items. The foreseen third step, which will be soon applied, reduces the items around 35.

1.5.1 First Study

Sample: 500 subjects (250 male; 250 female)
Nationality: Italian
Age: 18–35
Time: 1 h for each subject (40-min trials + 20 min to complete the questionnaires within 5 min after the end of each experience)

The test was made on a set of daily experiences for each participant evaluating Presence and Flow. At the end of each "trial," the subject filled in the questionnaire.

This is the battery of the trial:

- Read a narrative description of a tennis match (10 min).
- Watch the television a registration of a tennis match (10 min).
- Play a tennis game using a static system console (10 min).
- Play a tennis game using a dynamic system console: Nintendo Wii Tm (10 min).

At the end, we analyse the data with SPSS software (www.spss.com) and a program to analyse the structural relation among the constructs. The more peculiar questions will be saved: 50/80 items.

1.5.2 Second Study

Sample: 100 subjects (50 male; 50 female).
Nationality: Italian
Age: 18–35
Time: 15 min to navigate and 5 min to fill in the questionnaire

For each subject, we have a session in an immersive VE. The environment is a model of an imaginary city. Azione s.r.l. (www.azionefilm.it) is the software house that developed the environment.

After the test, each subject, fill in the Presence–Flow questionnaire (the remaining items from the first version after the validation).

The sense of the second phase of the study is to verify the FPQ in an immersive VE context.

1.5.3 Third Study

Sample: 90 subjects (45 male; 45 female).
Nationality: Italian
Age: 18–35
Time: Each subject will navigate for around 15 min and 5 min to fill in the questionnaire.

The sample is divided in three group (30 for each group), a different environment is presented to each group.

Azione s.r.l. built a VR environment (an imaginary city) in three different version: (1) low-media quality and interaction, (2) middle-media quality and interaction, and (3) high-media quality and interaction. During the trial, for each subject, it was also measured an objective data using a non-invasive encephalogram (EEG) helmet.

For data analysis in the third study, we use SPSS software.

We expect to have an overall score of Presence and Flow in the group with higher-media quality and interaction mode, according to the theories.

The sense of this third phase of the study is on one hand verify the Presence–Flow questionnaire in different immersive levels; on the other hand, verify the strength of the subjective measurement (the questionnaire) through the correlation with the objective measurement (EEG helmet).

1.6 The Application: The FC

The FC allows the users to design a new production line or reorganize a preexistent one. The FC is composed of different modules, such as the planning table, the Web-based simulation, and the VE visualized by GIOVE. The FC is described in Part 3 of the book. The questionnaire was applied to the VE of the factory through which the user can design the production line.

The environment permits to add machines for designing the line and to select and link a product and a worker to the selected machine.

1.6.1 The Test

The FPQ was administered during different evaluation session of the FC environment. The expert presented DiFac result, its characteristics, and functioning. The data presented here collected information from Italy, Korea, and Estonia.

The following participants (38 total) provided feedback on FC environment by filling in the FPQ:

1. At ITIA, ten people who were not aware of the software.
2. Among academics and industrial people, 12 participating the CAD-CAM conference in Korea. It was the final public event for the Korean project.
3. Among academics and industrial people, nine participating in a lecture about Digital Factory and DiFac presentation at Tallinn University.
4. Eight people, mainly IT workers from Ropardo but not aware about the project.

1.6.2 Data Analysis

This section presents the analysis of the data collected from the FPQ. The participants rated their opinions against a series of statements using a Likert scale from 1 to 5 (Table 1.1):

Table 1.1 Likert scale for the Flow for Presence Questionnaire

1	2	3	4	5
Highly disagree	Quite disagree	Neutral	Quite agree	Highly agree

For each question, a mean score of 1–2 was perceived as bad, 2–3 as insufficient, 3–4 as sufficient, and 4–5 as good. The only exception is the value for the Flow General Index, which is analysed differently and should be around 0 to be good. All data from the questionnaires were collected in an Excel file and the means were calculated. The results are discussed as follows.

1.6.2.1 General Index Evaluation Experience: 4.72

The General Index Evaluation value is linked to both Flow and Presence evaluation. The index indicates the wish to repeat the experience. When the rate for the repetitiveness is higher than 3, generally the environment is good. The value higher than 4.5 indicates that the people enjoyed themselves in using the environment and would repeat the experience.

1.6.2.2 Presence General Index: 3.77

The Presence General is good being the value higher than 3. The FC appears in this version a general good presence level but some aspects can be improved. The participants felt a good emotional state: well balanced between personal internal state as influenced by the external environment. The question number 4 that is about the sense involvement has a low score (2.33) because the use of the FC through the PC modality involved mainly sight. The possibility to listen to something is limited to the collaboration section using the Skype modality for discussing the design with somebody else. Very positive is that the testers feel a very low level of boredom in using the environment (question 5 with 2.13 rate): This means that the test at a first test is interesting and imply a good attention level, actually the challenge level is good.

Symptom that the design of the environment is good is the answer to the question number 39: “The images blocked my activity.” The mean of this specific question is extremely low: 1.74. The quality of the design is one of the factors that help Presence level, as the paragraph 4.4 has already shown.

1.6.2.3 Flow General Index: 0.9318

The mean of these data is calculated in a different way and its value should be between −1 and +1, closer to 0 is better.

The index appears scarce, the people using the FC is not really experiment the flow state. In fact, as you can see from Fig. 1.3, the testers experiment anxiety even if not in high level.

This value appears with negative score because some related questions are negative and measure the so-called anti-flow (Massimini et al. 1987; Delle Fave and Massimini 1990, 1992). The anti-flow state is the antithetic or opposite condition with reference to the optimal experience. Investigating the anti-flow state is important to build a correct rating point in terms of measurement structural validity. For statistical rules, the flow general index is included between − and + 1.

"The flow is the state in which people are so involved in an activity that nothing else seems to matter" (Csikszentmihalyi 1990). Attention is fully invested in the task at hand, and the person functions at their fullest capacity. The subjective experiments the following characteristics:

- The merging of action and awareness
- A sense of control
- An altered sense of time

Reaching the optimal experience of Flow has the following characteristics:

- Flow tends to occur when the activity one engages in contains a clear set of goals.
- Flow causes a balance between perceived challenges and perceived skills.
- When perceived challenges and skills are well matched, attention is completely absorbed.
- Flow is dependent on the presence of clear and immediate feedback.

1.6.2.4 Skill Index: 2.82; Challenge Index: 3.757

Reaching the optimal experience requires a balance between the challenges perceived in the specific situation and the skills the person brings in it. Challenges are potential factors inside the environment that can facilitate or obstacle the quality of the experience. Skills are potential abilities that the subject can bring in the environment. A good balance between these two states the flow indicators here above listed are assured. When the challenges are high and skills low, the experience produces anxiety rather than flow.

The items related with challenge index have a score nearly on 4 (agree with the sentence), only one has a lower rate: "The activity I was carrying out was encouraging me and it represented an opportunity and an effort to express myself and act." The environment does not appear as an opportunity for a self expression. On the other hand, the FC has specific rules for designing the production line; it is not something that can be used for expressing personal creativity.

The lower rate for skill question is for: "During the experience, response to my actions blocked the progress." According to Csikszentmihalyi, an equilibrium of challenges and skills often occurs in the activity when the goals appear relatively clear and providing rather quick and unambiguous feedbacks.

1.6.2.5 Disorientation Index: 1.44

Disorientation level changes depending on the type of VE, the hardware (HMD, gloves, glasses, etc.), and personal sensitivity of the vestibule system. Here is really low, because all tests were made using PC/mouse. The disorientation level of the FC is really low proof of that is the "malaise" questions (number 16) that have a rate of 1.28.

We test people after using the environment on a PC (both desk and lap top) because the results presentation was given at users' premises and none of them has a cave system or a virtual room at their sites. In any case, one of the main objectives was to demonstrate how DiFac technology could be portable and the FC on a laptop results to be user oriented. For the future, will be interesting to have same questionnaires after the interaction with FC through the CAVE, using a 3D mouse and glasses this will check the disorientation level using different hardware.

1.6.2.6 Coping Index: 3.47

Coping rate is strictly linked with the ability to manage unforeseen situations, find the solution to unexpected situation or problem. Human beings react to the unexpected situation in different ways: denying the situation, rationally facing the different aspects of the problem, and rebalancing the sense of the experience. Many people passing through the three states before arriving the third one that is the more positive one.

The coping level is good, in particular, the testers were strongly agree with the proposition "During the experience, I was able to solve the majority of the issues if I applied the necessary effort," it means the skills level/quality of the people is something really important for reacting and learning how to face problems.

1.6.3 Results and Future Development

In summary, the environment has a good rate for Presence, and the testers will be happy in repeating the experience. The absence of sounds compromises the natural use of the environment; the suggestion is to add some sounds natural for the factory to have the single user more engaged in a non-mediated word, the industrial "clang" could be cut whenever a collaborative session started for allowing the users to use the Skype conference tool. The repetition will make the users' skills higher, and the experience can reach characteristics nearer to the Flow. Suggestions for developers are:

- Clear set of goals in the environment
- Merging of action and awareness
- Increasing subject's sense of control
- Clear and immediate feedback, step-by-step completing different duties

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Chapter 2
Ergonomics Methods and the Digital Factory

Glyn Lawson and Mirabelle D'Cruz

Abstract This chapter discusses the ergonomics approach used to develop the digital factory solution for the European-funded DiFac project (IST-5-035079). The main aim of DiFac was to develop an innovative solution for small-to-medium enterprises which, based on a foundation of good human factors, would support their activities in the digital factory. Ergonomics focuses on understanding people and their capabilities to improve their interaction with hardware, software, other people, and their environments. The ergonomics approach of participatory design was applied to the iterative development of the technologies. This chapter describes this approach and the ergonomic methods selected to assess the various iterations of the DiFac technologies. A case study is provided illustrating the specific improvements to an emergency training simulator arising from the ergonomics approach. The chapter concludes with a discussion about the importance of these methods, and their associated difficulties, for this type of project and a summary of recommendations.

2.1 Introduction

Ergonomics (often synonymous with human factors) has been defined by the International Ergonomics Association as the "scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to

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optimize human well-being and overall system performance" (IEA 2000). One of the key aspects of the European-funded project DiFac (*Digital Factory for Human-Oriented Production System*: IST-5-035079) was to develop an integrated digital factory using good human factors principles to ensure the success of the project. As discussed in Wilson (2005), the lack of consideration of human factors has been highlighted as a main reason for the failure or limited success of information and communications technology projects. Specific contributing factors can be attributed to the following: unclear definition of the development process and end users' requirements; insufficient user training and support; a process which is too technology driven and inflexible, resulting in overly complex systems with too much functionality; and poor interfaces that do not match the needs of the user. It is widely recognized within the ergonomics literature that accounting for user needs during conception, design, implementation and operation of a product is critical to its success (McClelland and Fulton Suri 2005).

For these reasons, the human factors approach of participatory design was applied for the iterative development of the DiFac technologies. This chapter describes the participatory design process and the methods selected to assess the various iterations throughout the development cycle. It includes a discussion about the implementation of these methods for use during the development of information and communications technology solutions.

2.2 Participatory Design Approach to Development

The development process of DiFac was based on human factors best practice in conjunction with an appropriate method for designing new technologies. Participatory design is a user-centered approach, which highlights the importance of relevant stakeholders, in particular the involvement of end users, throughout the development process (Haines et al. 2002; Vink et al. 2002). Users can provide an important contribution to the process as they have tacit knowledge resulting from their familiarity with the workplace, task, or equipment. This means that they have unique insight into working processes and are thus likely to identify potential problem areas (and possible solutions) in a new design. The essential elements of a participatory design approach are that the relevant stakeholders (designers, end users, and management) progress step-by-step toward the end result, which should be a more efficient, healthful, and comfortable design. During and after each step, all the participants should be informed of the progress and outcome in consistent ways (Vink et al. 2005). This approach not only ensures the technology matches end users' needs but also increases their acceptance of the final solution through their increased sense of ownership by active participation in the design.

The participatory design approach was used in combination with an agile method for developing the technologies. Agile methods (Cohen et al. 2004) are well known in software engineering and recommend small iterative cycles of rapid development with generally small self-organizing teams. This process enables design changes to be made early when less costly and continual progression is being made toward a solution that will address the users' requirements.

In the formative stage of development for each of the main DiFac technologies, four to five iterations were made and at each stage, an ergonomic assessment was conducted. When working prototypes were available, a user group evaluation session and on-site evaluation sessions took place. A variety of conditions was used for the evaluations as discussed later in this chapter.

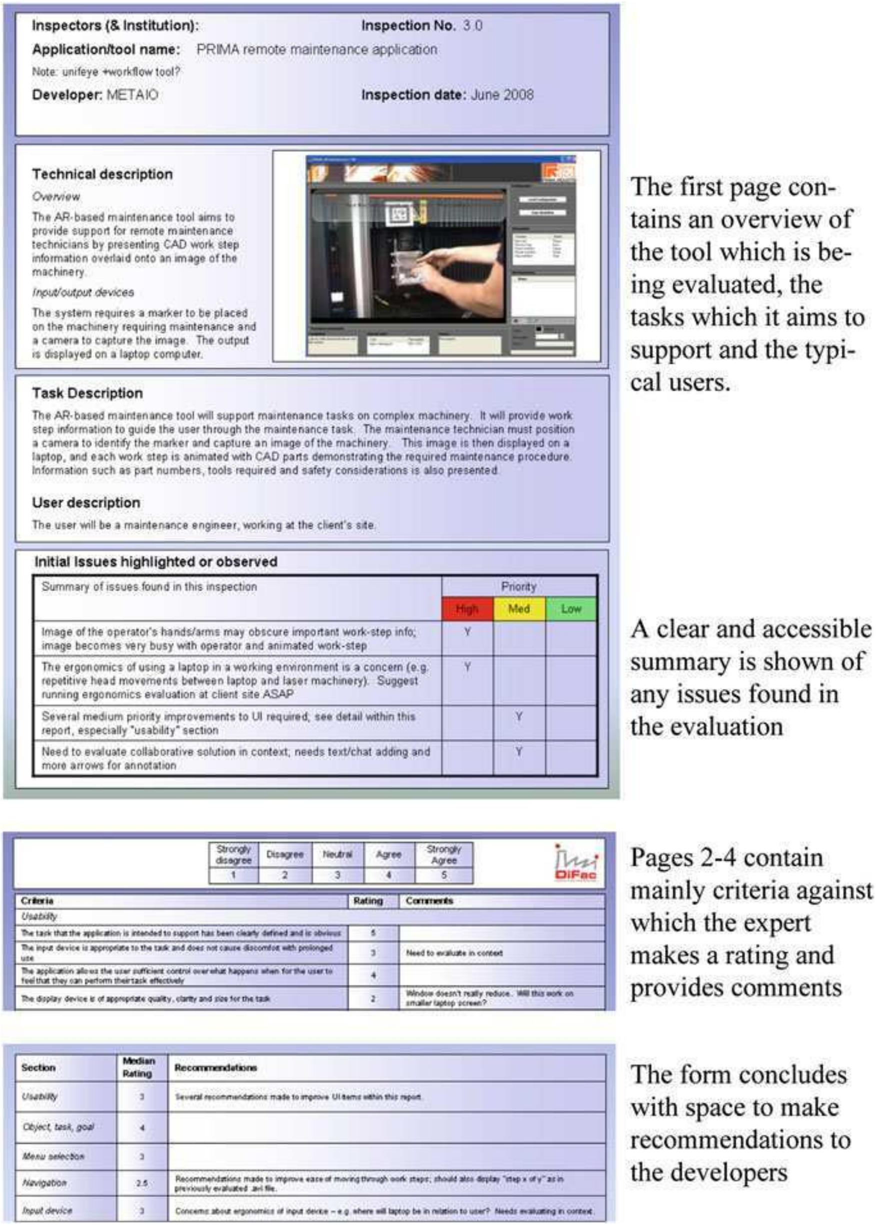
2.3 Selection of Appropriate Methods

A wide variety of validated ergonomic methods are available to assess a number of issues related to usability and effectiveness. As in best practice, the methods selected for DiFac were largely based on the target user group—small-to-medium enterprises (SMEs). SMEs have specific restrictions related to time and personnel. For example, in a company consisting of ten people, it may be necessary for each person to adopt a variety of roles (production manager, safety officer, salesman, etc.). This can benefit the development process as one person can represent a number of stakeholders and can provide feedback that is highly relevant across the activities of the company. However, a disadvantage is that although the person is in the development process, the workforce has been reduced by 10% for a certain period of time and in a participatory design and agile process, this has to occur at regular intervals. Therefore, the methods selected had to be easy to understand, quick to complete, and yet provide enough feedback for the developers to ensure progress of the project toward meeting the needs of the users. The methods selected were as follows:

Expert input: Throughout the development process, a human-factors expert participated in frequent meetings to provide expert knowledge and to identify any major usability issues. These meetings were supported by partners responsible for the technical development of the DiFac solution, industrial end users, and project management.

UNott heuristics checklist: Heuristics are rules of thumb that people follow to make judgments quickly and efficiently (Stanton et al. 2005). The heuristics checklist was based on the VIEW-IT (Tromp and Nichols 2003) assessment tool, which was originally developed to support the evaluation of usability, input/output devices, and health and safety risks associated with virtual environments. The DiFac tool was designed specifically for expert evaluations by human-factors specialists as well as extending the original tool for use on both desktop and virtual reality/augmented reality solutions. The intention was to design it such that it can be applied throughout the development of a system, yet provide high inter-assessor reliability, validity against other ergonomics methods and a clear and understandable reporting format for developers to use after the evaluation. Extracts from this are shown in Fig. 2.1.

Systems Usability Scale (SUS) checklist: This evaluation tool was selected as a quick and easy method to assess usability (Brooke 1996). SUS comprises ten



Inspectors (& Institution): **Inspection No.** 3.0

Application/tool name: PRIMA remote maintenance application

Note: unifeye +workflow tool?

Developer: METAIO **Inspection date:** June 2008

Technical description

Overview

The AR-based maintenance tool aims to provide support for remote maintenance technicians by presenting CAD work step information overlaid onto an image of the machinery.

Input/output devices

The system requires a marker to be placed on the machinery requiring maintenance and a camera to capture the image. The output is displayed on a laptop computer.

Task Description

The AR-based maintenance tool will support maintenance tasks on complex machinery. It will provide work step information to guide the user through the maintenance task. The maintenance technician must position a camera to identify the marker and capture an image of the machinery. This image is then displayed on a laptop, and each work step is animated with CAD parts demonstrating the required maintenance procedure. Information such as part numbers, tools required and safety considerations is also presented.

User description

The user will be a maintenance engineer, working at the client's site.

Initial Issues highlighted or observed

Summary of issues found in this inspection	Priority		
	High	Med	Low
Image of the operator's hands/arms may obscure important work-step info; image becomes very busy with operator and animated work-step	Y		
The ergonomics of using a laptop in a working environment is a concern (e.g. repetitive head movements between laptop and laser machinery). Suggest running ergonomics evaluation at client site ASAP	Y		
Several medium priority improvements to UI required; see detail within this report, especially "usability" section		Y	
Need to evaluate collaborative solution in context; needs text/chat adding and more arrows for annotation		Y	

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Criteria	Rating	Comments
Usability		
The task that the application is intended to support has been clearly defined and is obvious	5	
The input device is appropriate to the task and does not cause discomfort with prolonged use	3	Need to evaluate in context
The application allows the user sufficient control over what happens when for the user to feel that they can perform their task effectively	4	
The display device is of appropriate quality, clarity and size for the task	2	Window doesn't really reduce. Will this work on smaller laptop screen?

Section	Median Rating	Recommendations
Usability	3	Several recommendations made to improve UI items within this report.
Object, task, goal	4	
Menu selection	3	
Navigation	2.5	Recommendations made to improve ease of moving through work steps; should also display "step x of y" as in previously evaluated .avi file.
Input device	3	Concerns about ergonomics of input device – e.g. where will laptop be in relation to user? Needs evaluating in context.

Fig. 2.1 Extracts from the UNott heuristics checklist

statements relating to system usability, against which the user evaluates the extent to which they agree or disagree on a 5-point Likert rating scale. The ratings can be combined to give an overall measure of system usability.

General questionnaire: A questionnaire consisting of broad and exploratory questions was used to gather feedback on the proposed solutions. The questions were short and open and included the following: Is there anything you particularly like about the system? Is there anything you particularly dislike about the system? Do you have any recommendations for improving the system? Do you have any other feedback? This questionnaire could be given in addition to the methods listed above, but could also obtain useful feedback as a standalone method if time was limited. It was useful as it was short and the respondent could add as much or as little detail as required or as time permitted, which caused minimal disruption to the participants from their daily work.

2.4 Application of Methods and Discussion of Use

The evaluation of the main DiFac technologies took place in iterations. The iterative process was used to identify the strengths and weaknesses of the design before implementation. The major goal was therefore to increase effectiveness by providing good design guidance during development and identifying any major usability issues. This cumulated in a final evaluation involving SMEs and implementing the technologies at the DiFac user-partners' sites. The implementation of the methods is discussed in the following.

2.4.1 Weekly Technical Meetings

Pivotal to the success of DiFac were weekly technical meetings, typically held using on-line technologies, such as "Teamspeak" or "Skype". Wiki technologies were also employed to store actions, meeting minutes, executable files, and reports. The initial meetings began following user requirements capture with the industrial partners of DiFac. Three industrial partners—PRIMA, PPS, and COMPA—provided case studies of their application needs related to product development, factory design and evaluation, and training. Prima Industries S.p.A. (PRIMA) is a major company for the development, manufacture, and marketing of robotic laser cutting equipment. PRIMA explained their requirements for the collaborative design of laser machinery and also training support for remote maintenance of the laser machines. P. Pashalidis & Sons S.A. (PPS) is a privately owned textile industry who attended the weekly meetings to describe their requirements for collaborative product design and demonstration and factory design and evaluation. COMPA manufacture components mainly for automotive applications and their requirements included factory design and evaluation in response to increasing production targets. For more information on the user partners, please refer to "Part IV: DiFac Industrial Case Studies".

The input from the industrial partners generally included a brief description of their current activities and any perceived problems. From these case studies, lists of requirements were generated (Candea et al. 2008). The technical meetings progressed throughout the duration of the project.

The weekly technical meetings relied on ergonomics expert input for a variety of reasons. First, the experts' involvement could continually focus the discussions on the end users' requirements and prevent the development from becoming too technology oriented. Second, the expert could use this forum to organize the other evaluations, a process made easier through the involvement of developers, end users, and project management. Finally, these meetings were invaluable for presenting and discussing the outcome of the iterative evaluation stages, and again using the presence of key personnel to agree actions to address any issues.

2.4.2 Early Evaluation Sessions

Early evaluations were performed using short movie clips of possible technological solutions provided by the developers and based on the initial user-requirements. The industrial partners were able to access these clips then complete the general questionnaire. Enabling the end users to access the clips and questionnaire remotely allowed them to provide feedback in their own time. By consistently using the same short feedback form, the end users became used to the questions and were able to complete the form quickly with little disruption to their working activities. Arguably, the main benefit of this process was to capture users' opinions on possible solutions at a very early stage in the project. Video is a very accessible format, and users were willing to sit through a 2–3 min clip to gain an initial understanding of how the technologies could be used to meet their particular requirements. The process highlighted mismatches between the technologies and the users' needs and other potential issues.

When early working prototypes became available, the end users were asked to attempt a series of simple tasks (based on the anticipated end use scenarios) using the prototype system (e.g., view an image from the project files, create a new project, create and send a message, etc.). Again, these evaluations were conducted remotely, with the end users accessing the systems from their own sites, having received instructions and evaluation forms from the ergonomics experts. They were asked to record whether they successfully completed each task before being asked to provide ratings on the SUS checklist and completing the general questionnaire. The results from these provided a general identification of any problem areas, but the time limitations of SMEs prevented a more detailed evaluation. As an example, SUS asks the user to rate the complexity of a system: This can give an indication of the presence of too many complex features, or poor usability, but not specific recommendations that can be passed to the developers.

In parallel, and to address the lack of detailed recommendations from the remote user-evaluations, the UNott heuristics tool was applied by the ergonomics expert to highlight more specific usability issues. For each release of a video or prototype technology, the expert conducts a review against the four-page heuristic checklist. This evaluated aspects such as usability, input/output devices, collaboration, and VRISE (virtual reality-induced symptoms and effects). The tool requires that recommendations are made to address any issues found.

The combination of user testing and heuristics tool meant that user feedback could be obtained from time-pressured SMEs, from a remote location, and yet detailed recommendations could be provided to the developers. At an early design stage, it was possible to highlight potential usability issues and to gain useful end user feedback, even with simple examples of the technology. Evaluations with end users identified issues that were addressed easily because of the early stage in the development process. This was supplemented by detailed recommendations arising from the heuristic evaluation.

2.4.3 User Group Evaluation Session

When the individual DiFac technologies reached the working prototype stage, a user group evaluation session took place at PRIMA in Turin. The participants included the three representatives of the industrial case studies—PRIMA, PPS, and COMPA—and six representatives of the DiFac user group. This user group consisted of external groups to the project with an interest in the digital factory, including SMEs involved with manufacturing plastic packaging and robotics and also representatives from SME associations. In addition, there were 15 members of the DiFac consortium with a variety of roles from developers to human-factors experts.

Following a presentation of the project and of each of the technologies, participants were divided into small groups of three or four people. Each group was given a demonstration of the technologies and the opportunity to have some hands-on experience. With the support of an expert, they were given 10 min to explore the technologies before completing the general questionnaire.

This session was the first opportunity that developers had to discuss the technologies with external representatives as well as with the other developers. In general, the technologies were well received and potential could be seen by the external users in their own companies. A large number of recommendations were generated but the developers were able to see at first hand the actual problems that the users were experiencing and to discuss this with them further. Often, information in questionnaires can be limiting as the respondent may not have explained fully their response or it may be difficult for the evaluator to understand their response. A face-to-face evaluation session enabled the evaluator not only to see directly potential usability issues but also to question the participants further to have a more detailed response in informal interviews.

2.4.4 Final Evaluation

The design of the DiFac system was developed in response to the recommendations arising from the previous stages. The final evaluation aimed to assess the value of the DiFac solution at the end of the development phase. In particular, the aim was to evaluate the DiFac tools for supporting the jobs for which they were designed. The evaluation also included a broader range of SMEs, partly to obtain their feedback, but also to demonstrate the results of the project.

For this evaluation, the DiFac end users were asked to use the technologies, in their own workplaces, to support tasks typical of their core business activities. This was essentially a summative evaluation, concerned with judging the value of the DiFac solution. By this stage, it was appropriate to expect more time commitment from the user-partners, particularly as the solution was almost ready for deployment in supporting their work tasks. Therefore, they were asked to recruit user panels of at least five people to feedback on the relevant components. They were also issued with evaluation packs, containing detailed instructions, task lists to attempt, and evaluations forms, including SUS and the general requirements questionnaire. Consistent with the anticipated end use of DiFac, the technologies were set up remotely, with the user-partners downloading themselves user manuals and any required executables. This important decision made the implementation more realistic than had an evaluator attended the user site to conduct these activities themselves.

In addition to the user-partner evaluations, a broader range of SMEs and SME associations participated in evaluation of the DiFac technologies. Participants were given a demo of the DiFac technologies (either using a video of the solution in use or a live demo by a DiFac representative) followed by an opportunity to ask questions. They were then asked to complete the general questionnaire to provide feedback on the technologies. A combination of qualitative and quantitative methods was used, combining exploratory feedback on likes, dislikes, and suitability for the SMEs' needs, with quantitative ratings on overall impression of the DiFac solution. Overall, feedback from the SME participants was generally very good, supported by ratings that were all positive. Aspects well-appreciated include the user friendliness of the system, the collaboration features, and the high level of presence offered by the tools. The SME participants also liked that the solutions were lightweight and could run on standard equipment.

2.5 Case Study: Development of the Emergency Training Simulator

This section provides specific examples of the changes made to the emergency training simulator as a result of the process described above. Figure 2.2 shows the appearance of the user interface of the simulator at the start of the DiFac project.

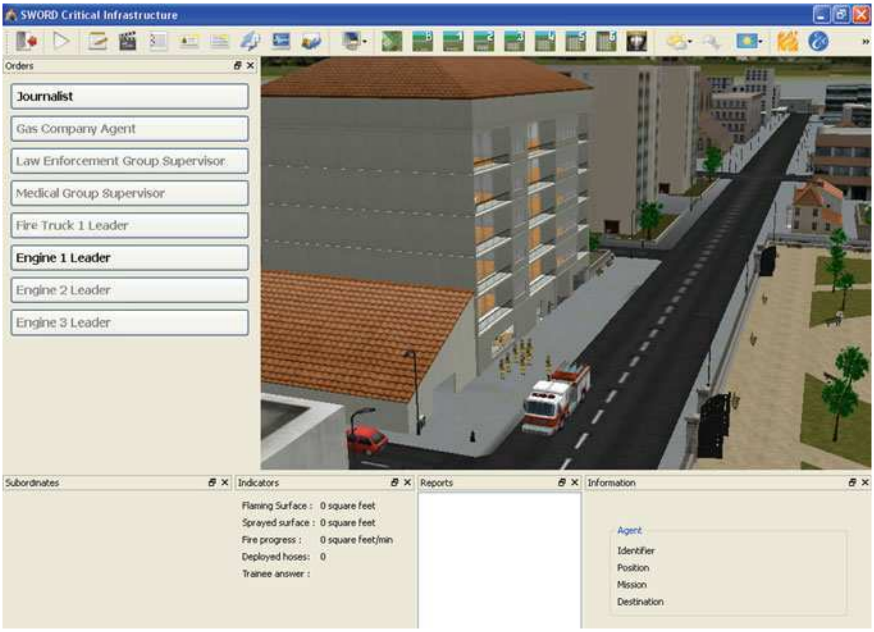


Fig. 2.2 Early user interface of the emergency training simulator

At this stage, the implementation was focused on training the commander of an emergency response scenario. The trainee issues orders verbally and these are input through the user interface by a trainer. The trainee witnesses the emergent scene as shown in the main simulation window in Fig. 2.2. Through the course of the project, it became apparent that the solution should be focused more specifically on the needs of SMEs, specifically for training factory employees in emergency evacuation procedures. This consequently increased the importance of usability, as the employees are encouraged to self-train on the simulator, interacting with the system themselves rather than by issuing commands verbally to a trainer. Expert input was provided to improve the usability, for example, recommendations were made to simplify and improve the icon design and include text menus to help ease of understanding (see Fig. 2.3 for the final emergency training simulator design). Ergonomics input also included presenting video clips of the emergency training scenario to firefighters who provided expert feedback on the simulator. The results of these evaluations were presented during the weekly meetings.

At each development iteration, the UNott heuristics checklist was applied to the emergency training simulator. Identified issues included the time taken to load, which was quickly resolved in subsequent iterations. There were problems with information overload through the icons and windows surrounding the simulation environment—a marked improvement can be seen in Fig. 2.3. Other recommendations included improvements to navigation in the virtual environment through

Fig. 2.3 Final development of the emergency training simulator

illuminating the emergency exit signs and to improve the ease of moving through doors. An instructional video walk-through was also introduced as a result of problems with transferring information from the briefing page to the training. The results of the heuristic assessments were also fed back during the weekly technical meetings to discuss and identify solutions.

Toward the later stages of the project, the training simulator was assessed using SUS, which confirmed that there were no major usability problems. The evaluation also included SMEs, who were asked for feedback using the *general requirements* questionnaire. The simulator was generally viewed positively, with participants recognizing the convenience of a training simulator and also commenting positively on the appearance of the simulation.

2.6 Conclusion

A number of interesting conclusions can be drawn from this application of ergonomics methods to the development of a collaborative digital factory for SMEs. First, as our target user group was SMEs, this had a huge impact on the methods selected and the type of feedback possible to obtain. The number of potential participants available was small because of the nature of the organizations, but each participant represented a number of roles within their company. Therefore, it was felt that several perspectives were obtained when designing and evaluating the technologies and, in particular, the end users representing the evaluation provided good quality feedback. There was very limited time with users and the quick and easy methods selected (as opposed to in depth trials) were much more appropriate, and appreciated, as they reduced the requirement for long feedback sessions and long periods away from the workplace. The participatory design approach was useful as the frequent short meetings meant that the users could provide instant feedback without affecting the rest of their working time.

Second, obtaining end user feedback can be achieved effectively and efficiently. It was still possible to identify potential usability issues and to gain useful end user feedback, even at the early stages of development when only video clips or web-based prototypes of the software were available. Evaluations conducted remotely, without visiting the end users' sites, are still useful. Instructions can be administered through e-mail, and although this reduces control of the conditions under which the evaluation occurs, the evaluation can incorporate the input from several users in a short space of time. Furthermore, conducting an off-line evaluation means that should the end user have any difficulties with the test procedure, for example, being asked questions in their second language, they can take time to ask for help. They can also fit the evaluation around their everyday work.

Finally, although the end user feedback is vital, it was found to be worthwhile supplementing it with expert (or heuristic) evaluation. The end users cannot be expected to spend any significant length of time evaluating the systems because of the pressures of their routine jobs, and therefore a more detailed evaluation is recommended. For DiFac, heuristic evaluations resulted in recommendations that could not have been made based on the user feedback alone, including recommendations to improve the ease of navigation as well as recommendations to improve the comprehension of user interface elements.

The recommendations concerning the ergonomics methods and the digital factory can be summarized as follows:

- End user input is critical—get as much as possible and as early as possible.
- Consider end users when selecting ergonomics methods; for example, think about their availability to contribute to the evaluation process.
- Use a combination of methods; this can result in more detailed comprehensive data to input to the development process.
- Show the developers the users interacting with prototype technologies; this provides a clear and convincing demonstration of any issues.

The chosen evaluation procedure in DiFac focused on human factors and was therefore likely to have resulted in technologies that were more suitable for the end user than if a more technocentric development approach was applied. A variety of stakeholders were engaged in the development process and thus provided a sense of ownership and motivation to use the final solution. The need for "quick and easy" methods has been shown to be useful and appreciated by the respondents while still providing developers and industry with useful feedback. A heuristics checklist tool has also been developed that supported the ergonomics expert in providing more detailed feedback.

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Chapter 3
A Web-Based Platform for Collaborative Product Design, Review and Evaluation

Dimitris Mavrikios, Kosmas Alexopoulos, Vagelis Xanthakis, Menelaos Pappas, Konstantinos Smparounis and George Chryssolouris

Abstract This paper presents a web-based integrated platform, called collaborative prototype designer (CPD), which has been developed to support the collaborative product design activities. The CPD is part of an integrated collaborative manufacturing environment (CME) supporting team work in product development, factory design, and worker training within a Digital Factory framework. The CPD addresses the needs for collaboration, during the product development process, by providing functionality for collaborative product design, review, evaluation, and demonstration. The CPD consists of a web-based platform for content management and users' interaction, a tool for real-time collaborative geometry modeling, virtual and augmented reality platforms, and a tool for collaborative decision making. The use of the CPD is demonstrated by a real life design case, related to the development of a new laser machine. The CPD has a flexible architecture that takes into consideration the design needs of both mechanical and non-mechanical products and it is therefore considered being applicable to a wide range of products. It also integrates design activities, processes, methods, and tools into a modular feature easy to be used and further extended.

3.1 Introduction

Nowadays, product development is the result of a network-based collaborative process, because most of the projects require co-operation among geographically distributed expert groups with diverse competence (Chryssolouris 2006).

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A collaborative product design project should take into consideration issues related to the users' integration, organization, and communication, as well as product data sharing, management, and visualization. New and efficient paradigms of a web-based collaborative product design, in a global economy, will be driven by increased outsourcing, competition, and pressure to reduce product development time (Draghici et al. 2007).

3.1.1 Background

Computer-supported collaborative design has been a widely used term, describing the process of designing a product through collaboration among multidisciplinary product developers associated with the entire product life cycle. Several research activities related with the development of web-based methodologies and prototype systems for computer-supported collaborative design have been reported in the scientific literature (Shen et al. 2008). The collaborative conceptual design has been a major area of research work, mainly addressing several web- and agent-based approaches to support collaboration during the early stages of product development, conceptual design tools and frameworks, conflict resolution, and team/project management for conceptual design (Wang et al. 2002). Extensive research work on collaborative computer-aided design (CAD) has also been reported, addressing issues, such as co-design systems and feature/assembly based representations, web-based visualization, 3D representations for web-based applications, and 3D streaming over networks (Fuh and Li 2005). Several synchronous and asynchronous co-design systems, providing collaborative modeling functionality, have been developed. Most of them are based on the client–server model, while recently, some systems providing real-time online collaboration, based on a peer-to-peer network, have also been presented (Chen and Tien 2007). The integration of different commercial client CAD systems into a co-design platform has been demonstrated in some cases (Li et al. 2007). Virtual reality (VR) based systems for collaborative product modeling were also suggested in the past (Arangarasan and Gadh 2000; Shyamsundar and Gadh 2002). Shared product visualization and collaborative design review has been another major area of research and development work. Methods of sharing virtual product representations over the web and a number of CAD-integrated shared workspaces have been presented in the scientific literature for distributed design review (Sharma et al. 2006; Hren and Jezernik 2008). Shared VR-based environments have also been used to support interactive collaboration in product design review (Kan et al. 2001; Pappas et al. 2006; Chryssolouris et al. 2008). Most of the reported research activities focus on providing collaboration tools for specific phases of the product development process. Only few activities have demonstrated integrated solutions, capable of addressing interrelated phases of this process, such as modeling, review, and analysis (Li et al. 2004). Research works on Internet-based product information sharing and product data management (PDM) related applications have also been widely documented (Xu and Liu 2003; Zhang et al. 2004). Apart from product design issues, several researchers have also worked on the development of methods and tools to support real-time collaboration for distributed activities related to manufacturing and product assembly (Mahesh et al. 2007; Meng et al. 2006). The development of web-based manufacturing systems has also been extensively investigated (Yang and Xue 2003).

Moreover, several software vendors have launched in the market to support collaborative design activities (CoCreate OneSpace.net web pages http://www.ptc.com/products/cocreate/onespace-net, ENOVIA web pages http://www.3ds.com/products/enovia, IBM PLM Express Portfolio web pages http://www-01.ibm.com/software/plm/, Siemens Teamcenter web pages http://www.plm.automation.siemens.com/en_us/products/teamcenter/index.shtml).

3.1.2 Motivation

Despite the investment made in the recent years, both in research and in industrial applications, the global market still lacks integrated, flexible, and cost-effective solutions to support the collaborative product design. Most of the research-based solutions available focus only on individual aspects of the design collaboration process, e.g., by providing either web-based environment for collaborative PDM/product life cycle management or shared CAD/VR-based environments for collaborative product modeling or review. No research work has provided so far an integrated environment for collaborative data management, product modeling, review, and decision making. On the other hand, most of the commercial solutions on hand are sophisticated, large-scale, and off-the-shelf tools, which are typically very expensive and not easily customized. In this way, small and medium enterprises (SMEs) cannot usually afford to integrate them into their product development process.

Thus, the research work described in this chapter has been focused on the development of a web-based platform for collaborative design, including real-time collaborative geometry modeling, interactive and immersive product visualization along with a smart decision support mechanism for collaborative design evaluation also enabling SMEs to benefit from these tools so as to improve the collaboration in the product development process, specially with original equipment manufacturers.

The collaborative prototype designer (CPD) system serves as a multiuser real-time collaboration tool for supporting product development activities and it could be used, as an efficient tool, by designers, engineers, managers, suppliers, and customers. It enables single users and/or user groups to work in a collaborative way, even if they are dispersed over different sites, without changing the existing design environment. It provides the necessary infrastructure to make engineering teams efficient, by improving their productivity, which results in decreasing considerably the time required for the designing phase to be completed. The key contribution of this system is its architecture that integrates the computer-aided design, VR/augmented reality (AR), and decision-making work space into a modular feature, easy to use and manage. Among the benefits that could be acquired by using the system are:

- Quick and easy product data storage and sharing through an easy to use web-based content management platform
- Synchronous and asynchronous communication among distributed individuals or user groups
- Real-time co-operation for the geometrical design of the product models
- Multiuser visualization and interaction with shared virtual product prototypes
- Decision support for the evaluation of the alternative product designs/variants
- Online demonstration and customization of products into a 3D interactive environment.

3.2 Digital Factory Framework

A *Digital Factory* is a rich virtualized environment that allows to:

- Represent a variety of product life cycle activities
- Share product development resources, manufacturing information, and knowledge
- Simulate the product, the production processes, and the factory operations
- Plan, produce, and manage among different participants and departments.

Both research and industrial communities have contributed to the definition of the Digital Factory vision and suggested how this vision could be implemented in the future (Bracht and Masurat 2005; Ad-Hoc Industrial Advisory Group 2009). In the respective works, collaborative design environments are typically considered as an inherent part of the future Digital Factory framework, integrating new tools to manage both the product and the process architecture, as well as to manage the interaction between the different teams involved in the design process.

The research work presented in this chapter aims to contribute to the implementation of the future *Digital Factory* vision. By providing web-based tools for collaborative product design, review, evaluation, and demonstration, it aims at supporting the evolution of the current design practices into a fully digital co-operative development engineering activity.

This work is part of the development of a collaborative manufacturing environment (CME) for the next generation of Digital Factories (DiFac 2009). The CME consists of an integrated framework for supporting team work in product development, factory design, and evaluation, as well as in worker training (Fig. 3.1). This framework is based on key aspects of the human factors of a Digital Factory, i.e., presence,[1] collaboration, and ergonomics. The CPD, being the

[1] *Presence* is a defining characteristic of a good VR system, a feeling of being there, immersed in the environment, able to interact with other objects there with a perceptual illusion of non-mediation.

Fig. 3.1 The collaborative manufacturing environment framework (IMS DIFAC EU Project)

output of the work presented in this chapter, is one of the major components implementing this framework for collaborative digital manufacturing activities.

3.3 Collaborative Prototype Designer Functional Architecture

The CPD functional architecture specifies the way the system addresses the collaboration needs of the product development process, within a Digital Factory framework (Fig. 3.2). This functional architecture is generic, taking into consideration the design needs of both mechanical and non-mechanical products and it is

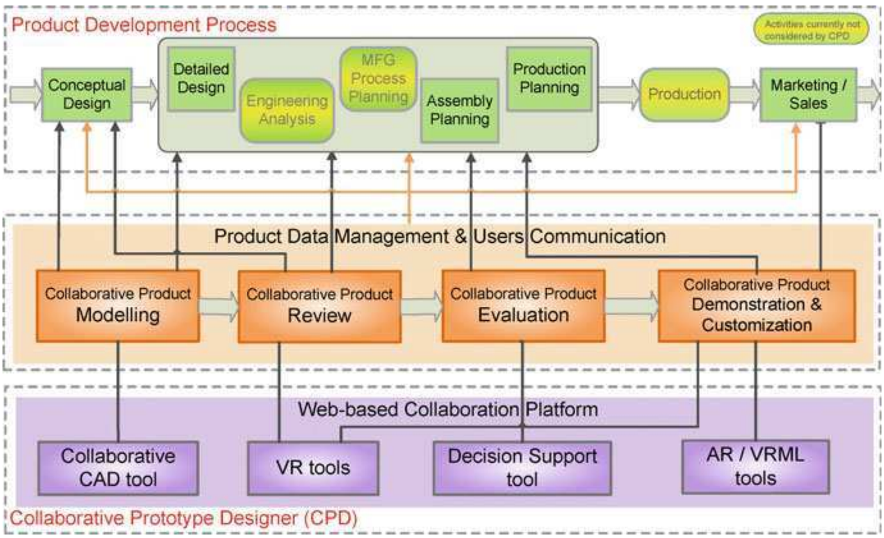

Fig. 3.2 CPD and the product development process (CAD computer-aided design, VR virtual reality, AR augmented reality, VRML virtual reality modeling language)

therefore considered being applicable to a wide range of products. The main functional steps within the CPD integrated system are:

PDM and users communication: The actors involved (designers, engineers, suppliers, etc.) can login into the CPD platform, review the product-related stuff, share files, and communicate in a synchronous or asynchronous way to share ideas, knowledge, opinions, and data. Using the central workspace, the users may access all CPD functionality using the respective interfaces for each module.

Collaborative product modeling: Within this step, the remote actors can have real-time, online, concurrent CAD sessions, using typical CAD functionality (e.g., design curves, surfaces, solids, etc.). The users participating in the collaboration session will have the capability of concurrently viewing and modifying the attributes of the geometry model. They are provided with the ability of real-time collaborative manipulation, creation, and modification of the product/part models and not just collaborative visualization. During a CAD design session, the end user may initiate a collaboration session with a given topic name. Other participants may join the collaboration session and have an online CAD collaboration. Then, all the CAD users, participating in the session, will be able to share and work concurrently on a common CAD model. However, each user has his own desktop and capable of selecting his own view plane, view angle, etc. Additionally, the user may select whether to automatically accept all model changes, submitted by the other collaborative users, or to manually check and verify each change in their model instance.

Collaborative product review: In the next step, users may create together the virtual prototype of the product by importing the geometry models, built during the collaborative CAD session. They are able to navigate, visualize, and interact with the virtual prototype, so as to review the different design solutions. Typical scene-building functions (e.g., lighting, add/remove geometry, coloring, and material selection, etc.) are provided. The product assembly sequence may be further built and simulated in the shared environment, for the impact of the design options on the product assembly process to be reviewed.

Collaborative product evaluation: Following a review session, remotely located actors may be engaged in a collaborative decision-making session, so as to reach a decision on the best of the reviewed alternatives. Multiple evaluation criteria and their respective weights may be defined according to the decision policy. Depending on the actors' role and technical background, different weights may be also assigned to them by the manager of the design project. The actors can then provide values for each criterion of each design alternative. The expert-based evaluation may be complemented by including a set of criteria that get values directly from simulation sessions carried out within the CPD platform or within the CME, e.g., related to the assembly or production planning. The output of the session is a relative ranking of the design alternative solutions, which allows the selection of the comparatively best one.

Collaborative product customization and demonstration: During the last step, the final product designs are ready to be uploaded to the online product catalogue.

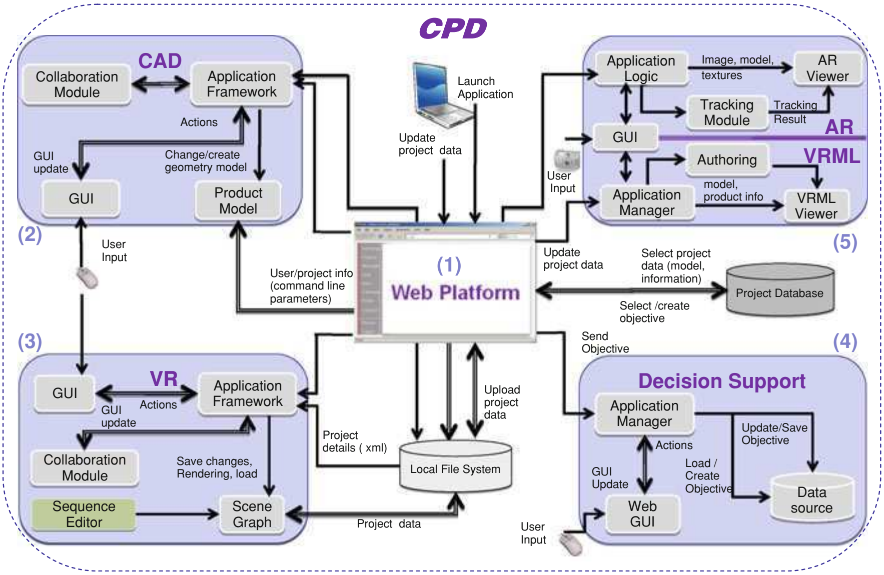

Fig. 3.3 CPD's components and user workflow

Customers would be able to use this functionality to explore, online, all the products available, in a standalone mode or within a 3D interactive environment.

3.4 CPD Component Architecture

The CPD is designed based on an open architecture and a browser/server technology that follows the three-tier example and includes: the data layer, the business layer, and the presentation layer. These layers communicate through the Internet or an intranet, depending on the type of communication. Oracle is used for the platform's database implementation, and for the connection mechanism among the mainframe PC and the application (JavaServer), the Java Bean Architecture, which contains the work division–planning algorithm and the database interactions. CPD consists of the following components, each one comprising several modules (Fig. 3.3):

1. The web-based collaboration platform that supports communication of the remote actors and PDM
2. The collaborative computer-aided design (CAD) tool that enables distributed real-time co-design of the 3D geometry models of the new product components
3. The VR tools that enable product design and assembly review within a shared VR environment

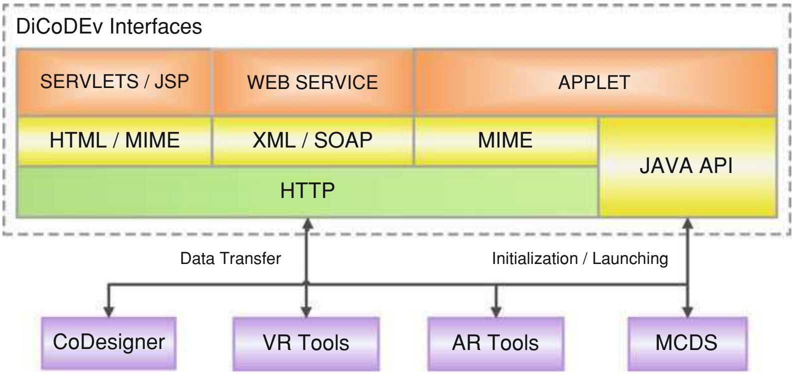

Fig. 3.4 Interface architecture

4. The decision support tool that supports the evaluation of the alternative design solutions, based on a set of criteria, and decision making
5. The AR/VR Modeling Language (VRML) tools that enable the interactive product demonstration and customization.

3.4.1 Web-Based Collaboration Platform

An "in-house" web-based platform (Distributed Collaborative Design Evaluation—DiCoDev) has been developed to support user authentication/authorization, data management/synchronization, and synchronous/asynchronous communications in CPD, based on some previous works (Pappas et al. 2006; Chryssolouris et al. 2008). The web platform consists of the following modules:

- *Authentication module*: This module provides security and blocks any unauthorized access into the system. Users should register first before being assigned by the platform administrator the proper rights and privileges of accessing the data and services of the electronic collaborative environment.
- *Communication module*: This module enables remote synchronous and asynchronous communication, such as VoIP (Skype), private/public chat, and e-mail.
- *Data management module*: This module provides a shared working space, user's roles, and access rights management. It also offers a mechanism for the automatic project file versioning; thus, providing the users with an easy way of keeping track of all recent modifications on product designs.
- *Authoring module*: This module enables the users to upload the new product models to the company's online catalogue, so that product information can be made available to customers.

The web-based platform also serves as the integrator of all the CPD components (Fig. 3.4).

```
-<xsd:CADCommand invoker="Designer2">
    -<xsd:SolidCreatePrimitiveConeTypical name="Acone" height="200" radius1="100" radius2="1">
         <xsd:basePoint x="0" y="0" z="0"/>
         <xsd:direction x="0" y="0" z="1"/>
    <xsd:SolidCreatePrimitiveConeTypical />
 </xsd:CADCommand >
-<xsd:CADCommand invoker="Designer2">
    -<xsd:ComplexCreateExtrudeTypical name="extrudedObject">
         <xsd:geoobject>article</xsd:geoobject>
         <xsd:axisdirection x="0" y="1" z="0"/>
         <xsd:height>150</xsd:height>
    </xsd:ComplexCreateExtrudeTypical>
 </xsd:CADCommand>
```

Fig. 3.5 Sample XML files

Agents have been used for the integration of the web platform with the collaborative CAD tool (CoDesigner) and the VR/AR tools. There are three types of agents, one for each module. Each agent "knows" how to communicate with the specific module and with the server. The data exchange is performed between the agent and the web-based platform. For each application instance, a user agent is created on the end user's computer, which handles data exchange as well as application initialization. On starting and closing the application, the agents participating in the same collaborative session make sure that each participant has the same product model with the one found on the web-based platform. In case an agent identifies incompatibilities in a physical file (i.e., a texture), then it requests the "server" version of the file, or it updates the server file to the local version, on closing the application, for future use. The data versioning is performed server side by the web platform.

The interface between the web platform and the multicriteria decision support (MCDS) tool is currently based on a parameter passing (similar to the other interfaces) through the http protocol, because MCDS is itself a web application. This interface is to be extended in the future to support the data exchange too, with the use of web services.

3.4.2 Collaborative CAD Tool

A collaborative CAD tool (CoDesigner) has been developed to allow users (product/part designers) to launch real-time, online, concurrent CAD sessions. The development approach has been based on a mechanism that translates typical CAD commands into XML files, which are transmitted to different CoDesigner application instances, that 'listen' to the same topic, and then are translated back into CAD commands. The main benefit of the "commands-based" approach is that the size of the data transmitted is small, because the geometry details (e.g., edges, vertexes, surfaces, etc.) are created locally, at each CoDesigner application and this usually huge amount of data is not transmitted over Internet. An example of the XML representation of CAD commands is given in Fig. 3.5. However, a limitation is that

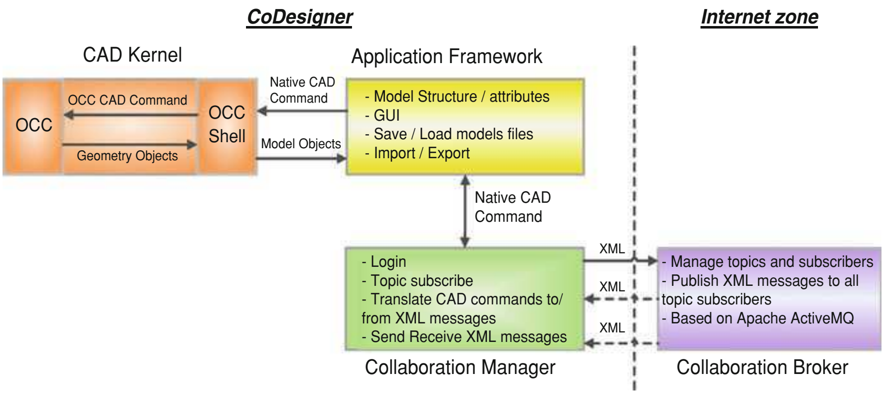

Fig. 3.6 CoDesigner s/w component architecture

for the application to be integrated into a heterogeneous CAD tools environment, a translation from the XML-based commands to a specific CAD tool command is required. Currently, the integration into other CAD systems is achievable "off-line" through the export and import of neutral formats, such as STEP, IGES, BREP, STL, and VRML. However, a real-time integration with other CAD systems using the "command-based" approach is feasible (Li et al. 2007), but would require further development of the CoDesigner, especially in the direction of translating the XML commands into native CAD commands for a specific CAD tool.

The CoDesigner consists of the following modules (Fig. 3.6):

- *CAD kernel*: The CAD kernel is based on the OpenCascade engine (Open CASCADE web pages http://www.opencascade.org/). It provides the required application-programming interface to create, manipulate, and visualize geometry.
- *Application framework*: This module provides access to the CAD kernel functionality, enables the management of the model information (load, save, select objects, etc.), and provides the end user with the necessary graphical user interface (GUI).
- *Collaboration manager*: This module handles the collaboration among different CoDesigner applications. It is responsible for translating native CAD commands into XML messages and sends those messages to the *collaboration broker* that is responsible for dispatching the messages to all the subscribed clients.
- *Collaboration broker*: This module is based on the Apache ActiveMQ message broker. Different CoDesigner application instances may communicate by subscribing and publishing topics in the server.

3.4.3 Virtual Reality Tools

The integration of a VR tool into the CPD allows users to create, share, and review, in a collaborative way, the virtual prototype of the product. A commercial

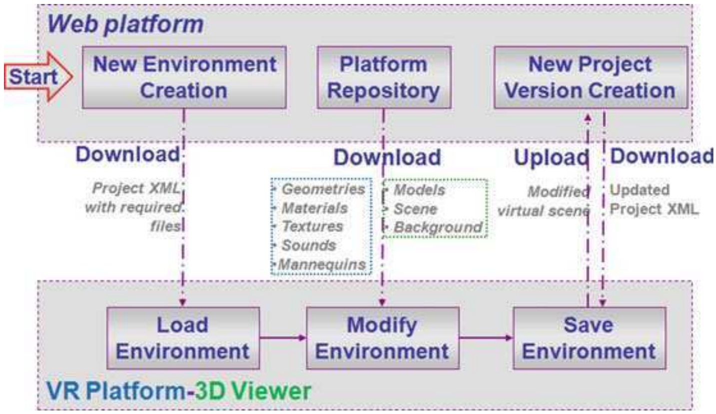

Fig. 3.7 Web platform-VR tools integration

VR platform (DIVISION Mock-up web pages http://www.ptc.com/products/division/mockup) and a non-commercial 3D viewer (GIOVE) (Vigano et al. 2007) have been integrated into the CPD platform and have been tested with different design review use cases. Customized user interfaces have been developed to facilitate user interaction with the virtual prototypes and CPD-related functionality.

The interface of the VR tools to the collaborative platform is implemented through the exchange of formed XML files. The users have the capability of downloading and uploading a virtual environment and their basic elements through the web (Fig. 3.7).

The VR tools are seamlessly integrated into the web platform, so as to be directly accessed through the platform's GUI. Through the web platform, users can initialize the VR tools in both a standalone and/or a client/server mode. The flexible and modular architecture of CPD allows the integration of other commercial or research VR tools that fit better to the design review needs.

3.4.4 Multi-Criteria Decision Support Tool

Based on some background research work (Chryssolouris 1987; Chryssolouris et al. 1994; Chryssolouris et al. 2000; Alexopoulos et al. 2007), an MCDS tool has been developed to provide decision-making assistance to a group of experts, in the final phase of their collaborative product design, by evaluating and comparing alternative product designs. The MCDS workflow is separated into three distinct phases:

- *Configuration phase*: In the configuration phase, a user may configure the details of an evaluation process. The details include:

- *Criteria and their weights*: Based on the decision policy, the manager of the design project identifies a set of criteria $\mathrm{CR} = \{\mathrm{cr}_1, \mathrm{cr}_2, \ldots, \mathrm{cr}_N\}$ by their weights $W = \{w_1, w_2, \ldots, w_N\}$, where N is the number of criteria. A criterion may be a benefit or a cost one. Should it be a benefit criterion, then the high values indicate its good performance, whereas if it is a cost one, high values indicate bad performance.
- *A list of alternatives* $A = \{a_1, a_2, \ldots, a_M\}$, where M is the number of alternatives. The alternatives indicate the different design solutions that should be evaluated.
- *A list of evaluators* $E = \{e_1, e_2, \ldots, e_S\}$, where S is the number of evaluators. The estimators may be other users that will evaluate the alternatives to the configured criteria. Moreover, for each evaluator, a list of weights $\mathrm{EW} = \{\mathrm{ew}_{11}, \mathrm{ew}_{12}, \ldots, \mathrm{ew}_{1N}, \ldots, \mathrm{ew}_{S1}, \mathrm{ew}_{S2}, \ldots, \mathrm{ew}_{SN}\}$ is defined for each evaluator/criterion pair, depending on the evaluator's role and technical background.

• *Data entry phase*: Following this configuration phase, the participants of the collaborative evaluation session (evaluators) may indicate values for each criterion and design alternative. The output of this phase is a matrix $S_\mathrm{s} = \{s_{11}, s_{12}, \ldots, s_{1M}, \ldots, s_{N1}, s_{N2}, \ldots, s_{NM}\}$ for each evaluator s in $[1, S]$ that defines the score for each alternative/criterion pair.
• *Evaluation and report phase*: The final step is the evaluation of the alternatives, based on the evaluators' scores from the previous phase. Initially, the score of each alternative for each criterion is calculated by the average value of all the evaluators' scores. Thus, $\mathrm{SC}_n = \{\mathrm{sc}_1, \mathrm{sc}_2, \ldots, \mathrm{sc}_N\}$ is a vector with the scores of alternative m in $[1, M]$ for all N criteria and

$$\mathrm{sc}_{mn} = \frac{\sum_{s=1}^{S} \left(s_{smn} \times \mathrm{ew}_{sn}\right)}{S}. \tag{3.1}$$

Then, the values of each alternative/criterion pair are normalized. The normalized values are given in case of the benefit criterion by equation

$$\overline{\mathrm{sc}}_{mn} = \frac{\mathrm{sc}_{mn}}{\sum_{m=1}^{M} \mathrm{sc}_{mn}} \tag{3.2}$$

and in case of the cost criterion by equation

$$\overline{\mathrm{sc}}_{mn} = \frac{1}{M-1}\left[1 - \frac{\mathrm{sc}_{mn}}{\sum_{m=1}^{M} \mathrm{sc}_{mn}}\right]. \tag{3.3}$$

The utility (final score) of each alternative is calculated by the weighted sum of the normalized scores as follows:

$$u_m = \sum_{n=1}^{N} \left(\overline{\mathrm{sc}}_{mn} \times w_n\right) \tag{3.4}$$

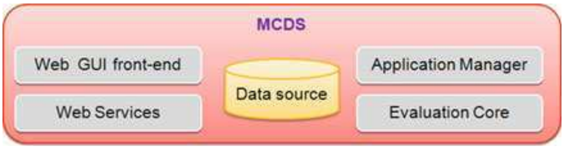

Fig. 3.8 MCDS s/w component architecture

As an output, the decision engine reports a relative ranking of design alternatives u_m.

The MCDS tool is running on a web applications server (Apache Tomcat) and it is composed of the following modules (Fig. 3.8):

- *Evaluation core*: This module is responsible for the calculation of each alternative's score. Its input is a list of alternative solutions, a list of criteria with their relative weight, a list of evaluators, and the scores of the evaluators for each alternative-criterion pair. The output is a ranking of the alternatives, based on the calculated scores.
- *Data source*: This module handles the persistency of the domain data. It uses XML as a means of storing and retrieving MCDS data. It is also responsible for the serialization of the data from the XML format into memory data structures and vice versa.
- *Application manager*: This module is responsible for managing the dataflow among the data source, the external actors (such as end users and other applications), and the evaluation core. Additionally, it provides basic security/login functionality.
- *Web GUI front-end*: This module provides a GUI through a web browser for the end users to use the MCDS functionalities.
- *Web services*: This module provides access to MCDS through the web services interface.

3.4.5 Augmented Reality/Virtual Reality Modeling Language Tools

The authoring module of the web-based collaboration platform enables the users to upload the new product models to the company's online catalogue. VRML and AR viewers have been integrated to the web platform to enable the users visualize these product models for demonstration and customization purposes (Fig. 3.9). A free plug-in (BS contact) has been used to provide the required functionality for a VRML viewer. Through this viewer, users can explore the product's web-based catalogue and interact with it in a 3D mode.

A commercial AR platform (Metaio Unifeye web pages http://www.metaio.com/) has also been integrated into the web platform. Through a lightweight online

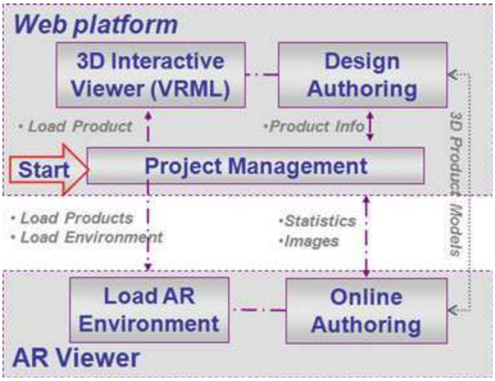

Fig. 3.9 Web platform: AR/VRML tools integration

application, CPD users can visualize the product models within real environments by creating mixed reality scenes that consist of realworld digital image data and virtual 3D models.

3.5 A Test Case

An integrated demonstration of the CME, in which CPD resides, has taken place, based on a real life–like scenario (DiFac 2009).

A manufacturer of laser cutting machines and systems (end user of the IMS DIFAC EU project) has provided the demonstration scenario and participated in the demonstration case study. The company's working practices on product development involve the use of a number of commercial tools (e.g., CAD modeler, viewer, PDM, etc.). The different actors, involved in a company's project, usually have to cope with different environments and with different software platforms. Everyday communications are mainly based on e-mailing and phone calls. When decisions have to be made, all the involved actors, such as R&D people, customers, engineering technicians, and managers, should meet physically. Thus, numerous trips need to be planned during a product development project.

The CPD-related part of the demonstration scenario involved the online collaboration during the modeling, review, and evaluation of new design solutions for specific parts/components of the machine and the interactive web-based demonstration of the new laser machine to customers. The online collaboration during the modeling, review, and evaluation of new design solutions for the tip-nozzle and the air-sensor tube of the new machine laser head is indicatively described hereafter (Fig. 3.10). The scenario framework of the collaborative design process is shown in Fig. 3.11. All the actors that were involved in the demonstration case study had received a daily training on the use of the CPD tools.

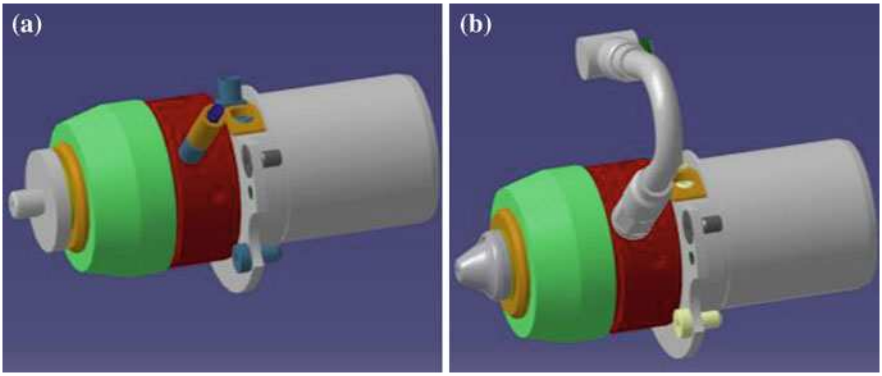

Fig. 3.10 The alternative design options addressed within the pilot scenario

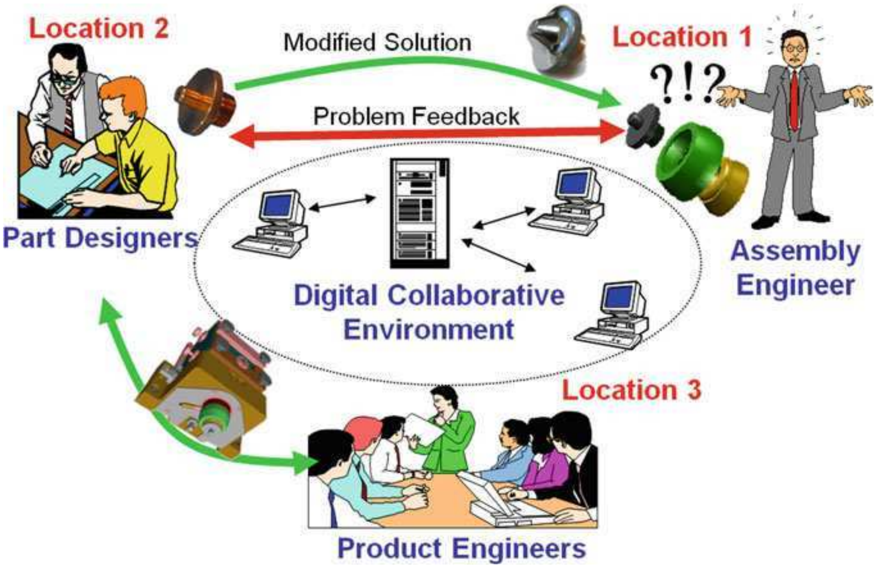

Fig. 3.11 The scenario framework for the collaborative design of a new part of the laser machine

The first step has been the launching of a design project for each new part and the assignment of the appropriate access rights to the people to be involved in it. A series of collaborative design sessions for the new parts of the laser head have then taken place. The web-based collaboration platform of the CPD has provided the users with content management and synchronous communication functionality throughout the overall process (Fig. 3.12).

First, a series of collaborative design sessions have been launched each one involving two remotely located designers. Based on previous experience and

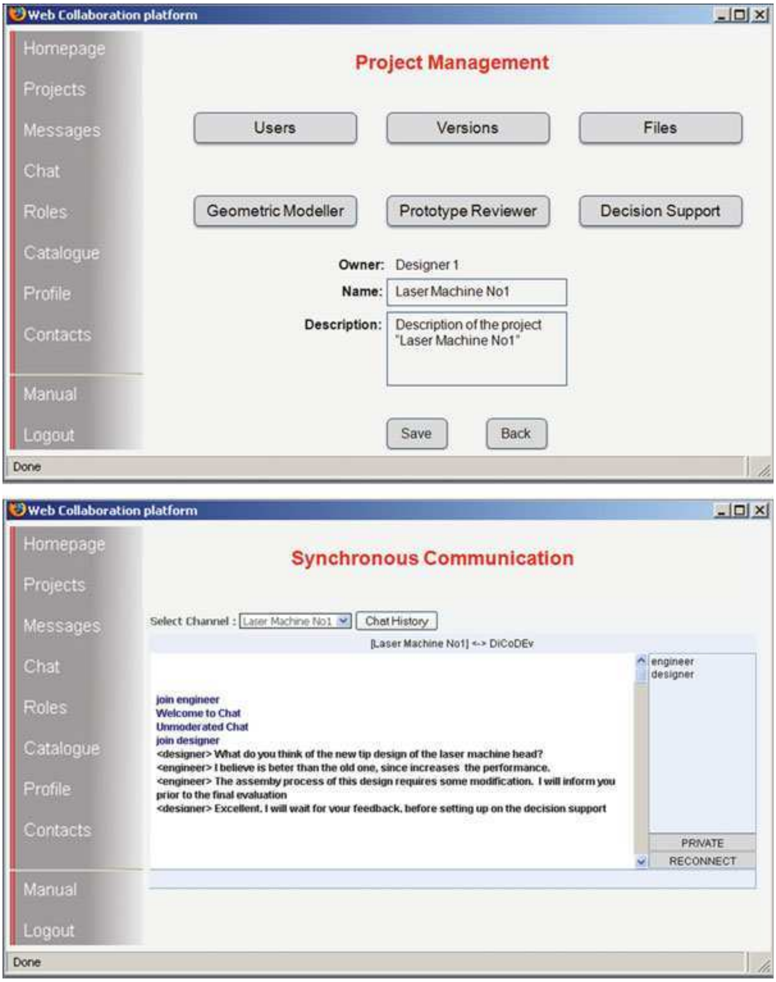

Fig. 3.12 Content management and synchronous communication in CPD collaborative sessions

market requirements about the new machine's features, the designers have used the CoDesigner module of CPD to create together the alternative design solutions for the tip-nozzle and the air-sensor tube. For each part, they worked together on the same model concurrently (Fig. 3.13). Each one creating, in real time, some specific parts of the geometry, while both viewing all the modifications incurred on the model and interacting with each other.

Concurrently with the design process, a series of collaborative sessions have been launched to be reviewed, at product and process level, the design alternatives being developed. The product manager, a designer, and an assembly engineer have been remotely engaged in each session. They have used one of the CPD VR platforms to share the virtual product models, including the newly developed parts,

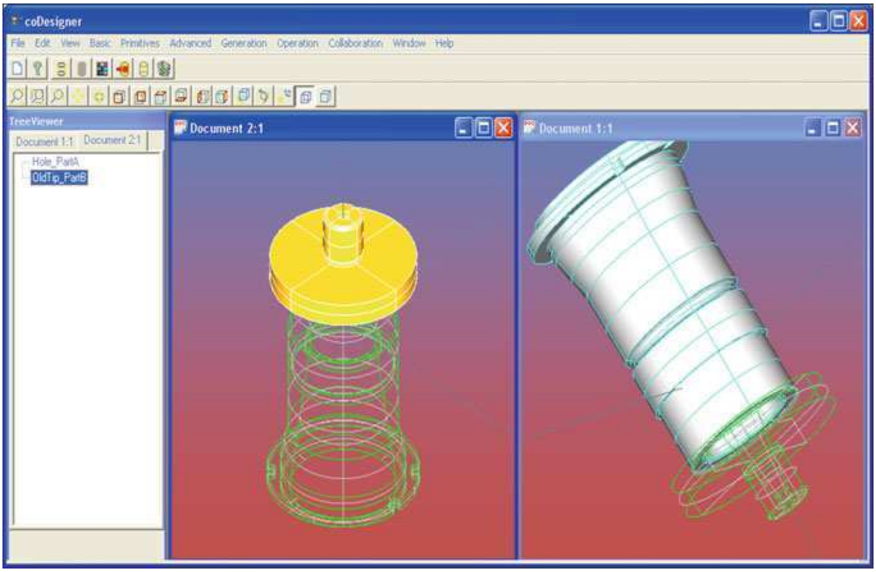

Fig. 3.13 Multiuser collaborative product design session

to visualize and jointly review the alternative options regarding the product structure and the respective assembly process, while interacting with each other for commenting on the design process output (Fig. 3.14).

Having followed the review sessions, it is evident that the selection of the best alternative design option for the new parts of the laser head is not a straightforward task, because several criteria could affect the final decision. Thus, a collaborative evaluation session has been launched for each of the two newly developed parts, using the MCDS module of CPD (Fig. 3.15). The product manager has defined the set of criteria, against which he has considered important the evaluation of the alternative design options, together with their relative weights. Five remotely located product engineers have been engaged in the collaborative session and indicated their expert-based assessment of each option with respect to its cost, performance, ergonomics, and aesthetics. Simulation data, coming from the factory constructor tool of the CME, have also been used for providing values of two additional evaluation criteria, namely, the total throughput and the average lead time. Based on the experts- and simulation-based inputs, the MCDS tool has provided a relative ranking of the design alternative solutions for each new part. Its metrics-based proposition has indicated that the design options shown in Fig. 3.10b are the good ones, with respect to the defined decision policy.

Finally, in the latest phase of the integrated CME demonstration, the CPD has been used for the interactive web-based demonstration of the new laser machine (Fig. 3.16). A product engineer and a potential customer have been remotely engaged in a collaborative demonstration session within the virtual

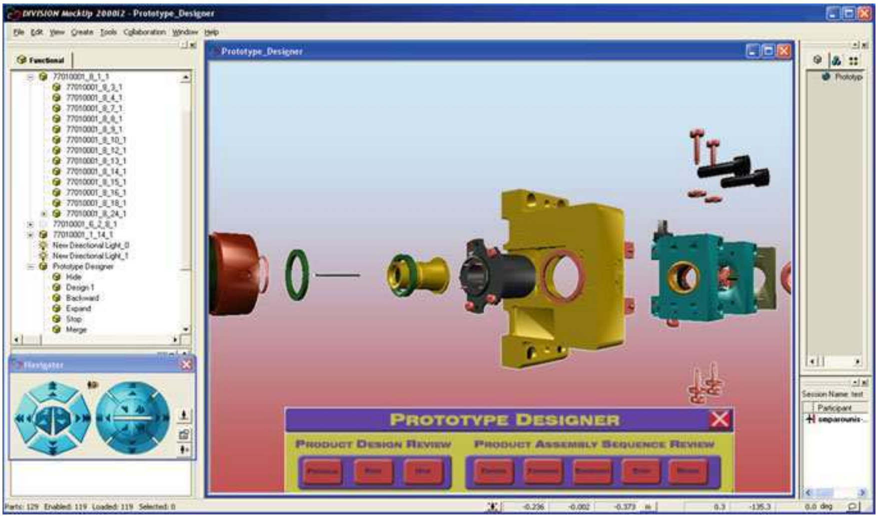

Fig. 3.14 Multiuser collaborative product review session

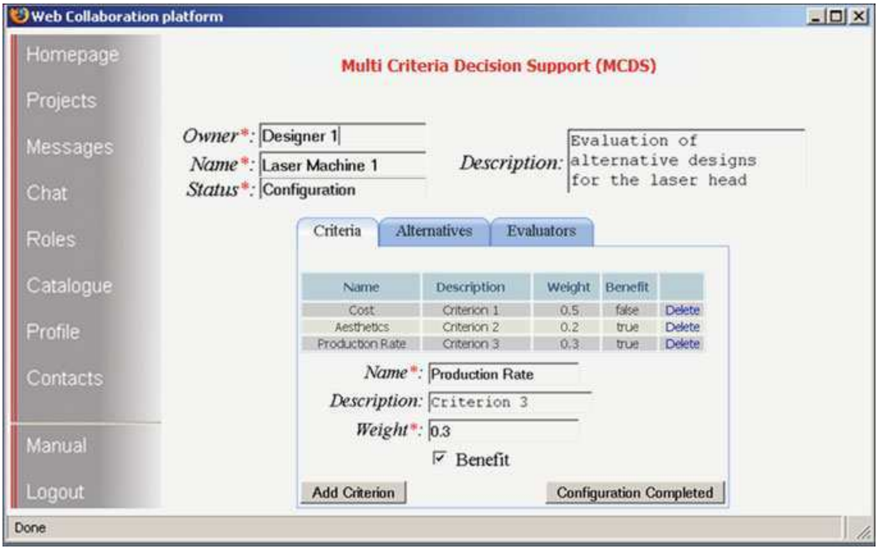

Fig. 3.15 Collaborative decision making for evaluating alternative solutions

showroom of CPD. Using the online product catalogue, offered by the virtual showroom, they have set up together the laser machine configuration. Then, they placed the machine within a virtual representation of the real working environment of the customer's facilities, reviewed together issues related with the work cell layout, ergonomics, and safety, and agreed on some required customizations.

Fig. 3.16 Online product catalogue (3D interactive) and multiuser showroom

Besides this demonstration case study, further testing of the CPD has been carried out in the context of the IMS DIFAC EU project activities. The overall testing phase lasted approximately 1 year, including the evaluation of several versions of the related tools. This testing involved:

- Two industrial partners of the project, namely, a manufacturer of laser cutting machines and systems and a carpet manufacturer;
- A *users group*, comprising external industrial companies (mainly SMEs), which has been set up to account for a broader evaluation scope of all the tools developed by the project.

The main strong points of the CPD, as reported during the evaluation, included the collaboration functionality, the capability for multimode (CAD/VR/AR) visualization, and the overall user friendliness of the web- and VR-based platform. The main recommendations for improvement referred to the CAD functionality, the user interface of the integrated system, and the seamless integration of the individual tools. The industrial companies that participated in the evaluation process reported that the CPD clearly demonstrates a big potential to shorten the development cycle and reduce the development cost of their products. On the other hand, they reported that a couple of challenges still exist for the use of such tools by SMEs, such as the required customization to fit to their special needs and the high costs associated with the use of sophisticated hardware in case of special visualization needs.

3.6 Conclusions

The CPD provides different functionalities for real-time collaboration among geographically dispersed user groups during product design activities. It is an integrated solution for collaborative product modeling, review, evaluation, and demonstration. The CPD has a flexible architecture, which integrates design activities, processes, methods, and tools into a modular feature, easy to be used and further extended. It may be used for a wide range of products. As such, it may be considered an appropriate tool for SMEs that cannot usually afford in their processes to integrate a suite of sophisticated, large-scale, off-the-shelf tools. The CPD provides an integrated set of tools for:

- Real-time geometry modeling of the same part/component by multiple users (CoDesigner)
- Online interactive review and demonstration of mechanical and non-mechanical products (VR/AR/VRML tools)
- Systematic decision support within a collaborative product design environment (MCDS)
- User-friendly communication and PDM (web-based collaboration platform)

In the context of the DiFac project, the CPD has been tested by using realistic design scenarios for both mechanical (e.g., laser machine) and non-mechanical (e.g., carpet) products.

In the short term, further work will mainly focus on extending the CAD functionality of the CPD. The CoDesigner has been providing so far only standard 3D CAD functionality (compared with other world-class tools), because the focus has been mainly on the real-time collaboration capability. A real-time integration with other CAD systems, using the “command-based” approach, will be investigated for its usability to be further extended. Providing collaborative product review functionality, with respect to engineering analysis activities, would be important as well.

In the longer term, the aim would be to extend the CPD functionality to addressing some key relevant challenges of the future Digital Factory frameworks, such as:

- Interoperability, and consistency of data, information, and knowledge, across the different stages of design
- Extracting, interlinking, and using of knowledge from different simulation results and domains to support decision making
- Use of more intelligent product/process models providing predictive capabilities to further reduce the need for physical prototyping
- Synthesis methods to account for sustainability and holistic life cycle assessment during product development.

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Part II
Knowledge Acquisition, Modeling and Sharing

Chapter 4
Integration Framework and PPR^{+H} Hub for DiFac

Ju Yeon Lee, Gun Yeon Kim and Sang Do Noh

Abstract Product lifecycle management (PLM) is a manufacturing paradigm that allows engineering contents to be integrated with all business processes through the entire product lifecycle in the extended enterprise. It extends product, process, and manufacturing resource (PPR) content knowledge into other enterprise business processes by coupling e-business technologies with manufacturing engineering applications, such as ergonomic analysis. To achieve concurrent and integrated ergonomic analysis in PLM, an integrated schema and a supporting platform that includes the PPR and human are essential. In this chapter, PPR^{+H} is defined and suggested as an XML-based integrated schema to manage and integrate all the information necessary for ergonomic analysis. And, this chapter introduces the PPR^{+H} hub for DiFac integration. It can extract PPR and human information from diverse legacy systems of a company and integrate them with DiFac applications. This approach includes the PPR and human information in PLM, and also includes the relations among these elements.

4.1 Introduction

Manufacturers have made constant efforts to improve their efficiency and responsiveness in product development and production to meet the changing demands of worldwide customers. Therefore, concurrent and collaborative engineering in product lifecycle management (PLM) have been issued in most manufacturing companies. PLM is an innovative manufacturing paradigm that gives leverage to e-business technologies. This allows product contents to be

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developed and integrated with all business processes of a company through the entire product lifecycle in the extended enterprise. Engineering decisions can then be made with a full understanding of the product and its portfolio, which includes processes, resources, and plants (IBM 2002).

Concurrent and collaborative engineering involves team-based exchanges of useful resources for lifecycle engineering, and it aims at creating a shared understanding and knowledge that can be used to address common needs within concurrent engineering (Mills 1998). Digital factory is a common integrated model that can address all engineering functions and product, process, and resource (PPR) information in a company's manufacturing systems (Colledani et al. 2008), and can be good basic infrastructure for successful engineering collaboration.

Ergonomic analysis is essential for process planning, job design, design of tools/machines/equipments, and workstation setup. And human safety has become a key factor in most manufacturing industries. Therefore, the effective management of human information in digital factory is very important. Until now, human information has not been a focal point in most digital factory models in PLM, and usually the human is considered as one of the manufacturing resources (Kim et al. 2008). For these reasons, there is a strong need for PPR and human information management and integration.

In this chapter, we explain PPR^{+H}, an XML-based common schema for the effective and integrated management of digital factory model and information related to PPR and human, and PPR^{+H} hub as an integration framework for DiFac (*Digital Factory for Human-Oriented Production System*), which is an international collaboration project supported by IMS (IMS Project No. 05001). The PPR^{+H} hub consists of several PPR^{+H} integrators and commercial product data management (PDM) systems. Figure 4.1 shows concepts of integration framework for DiFac, including the PPR^{+H} schema and the PPR^{+H} hub.

4.2 Common Schemas in PLM

There are several common schemas for information management and exchange in PLM. PLM Services was developed by the eXtended Product Data Integration task force of the ProSTEP iViP Association and it was accepted by the Object Management Group (OMG) in April 2004 (Lammer 2005). This schema includes a server to map the system-specific structures of commercial PLM solutions, such as SmarTeam, ENOVIA, Winchill, and Teamcenter to XML. It then exposes endpoints for Remote Procedure Calls. PLM Services is completely compliant with STEP AP214 and defines an abstract platform-independent model (Feltes 2005).

Product Data Markup Language developed by the Product Data Interoperability project in United States is the most popular in researches that focus on a neutral file format supporting the exchange of product information (Kim et al. 2008). It is a standard neutral file based on XML and supports the exchange of product and

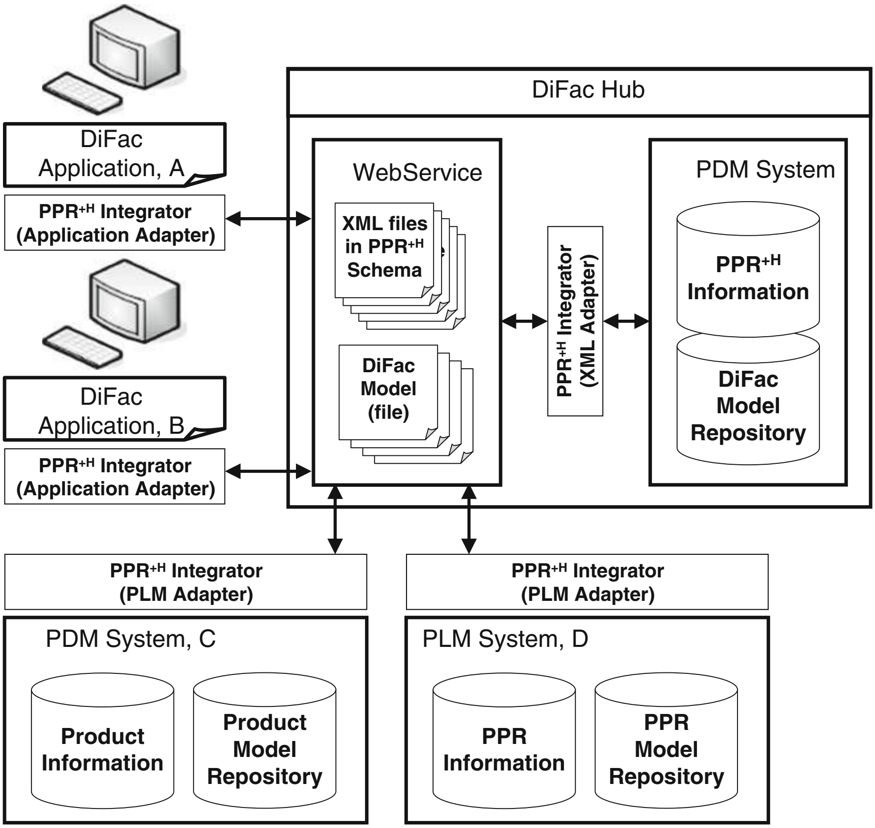

Fig. 4.1 Concepts of integration framework for DiFac

process information between PDM systems and other systems. Product Data eXchange standard is developed by IPC (Institute for Interconnecting and Packaging Electronic Circuits), focusing on the definition of bill of material information and exchange (Borgman et al. 2002). Process Specification Language standard is a result of an ISO project (ISO 18629) developed by National Institute of Standards and Technology. It is developed for the manufacturing process management in United States, and supports the exchange of process information (Schlenoff et al. 2006). Simulation Data eXchange is an XML-based standard neutral file format, and it aims at exchanging simulation data and information among different simulation software tools (Sly and Moorthy 2001).

In the area of PDM, there are also related researches. "Concurrent Engineering and Product/Process Data Modeling" carried out by ESPRIT (European Strategic Program on Research in Information Technology) is a good example of them. In addition, MfgDTF, a division in OMG, developed "PDM Enablers". It is a standardized interface for the object modeling of Infra-PDM to implement an integrated information environment (OMG 1998). Some researches focus on the management of product information based on the STEP. Yeh and Yoy (2002) proposed an integrated data model that refers to a STEP schema, along with an approach to implement a PDM system that uses STEP as a standard for the exchange of product data. Kim et al. (2006) defined product metadata through STEP PDM, and then applied it to the integration of applications and the implementation of Collaborative Product Commerce in virtual enterprises.

These researches did not consider the integration of all diverse information in PLM, such as product, process, manufacturing resource, and human. Usually, this information is defined and managed independently (Kim et al. 2008).

4.3 PPR^{+H}, XML-Based Schema for DiFac Integration

The purpose of the PPR^{+H} schema is to integrate and manage all models and information related to PPR and human in a digital factory. Figures 4.2 and 4.3 show a part of workflow model and information model for DiFac using Integration DEFinition (IDEF) language. To define a common schema for DiFac integration, we analyzed general engineering workflow of manufacturing companies, including product design, production planning, manufacturing system design, ergonomic/safety analysis and evaluation, and production. Then, we conducted workflow and information modeling of DiFac using IDEF methodology.

Figure 4.4 shows the concept of the PPR^{+H} schema for DiFac integration. It consists of five subschemas: product, process, resource, human, and PPRH relation schema having definitions of PPR and human relationship.

4.3.1 Product Schema

The product schema has parent and child elements representing the bill of material structure of a product. In this schema, the product structure is represented by “ChildItemRelation” and “ParentItemRelation”. If one of these parts has a subassembly or subparts, the “Item” element includes “ChildItemRelation”, which defines a unique “ID” of the child object, and “ParentItemRelation”, which has the “ID” of the parent one. “Archive” element represents information of the CAD file containing the geometric information of a part, such as location, format, size, and content. Other schemas for process, resource, and human also have this element. “Feature” element consists of “GripPoint”, “AssemblyPoint”, “TactPoint,” and other similar elements having information of coordinate system. “GripPoint” represents a gripping point for human hands and can be used for generating human postures in ergonomic analysis. “AssemblyPoint” contains a contact point between parts and the relevant coordinate information. “TactPoint” is a point of contact between a part and a manufacturing resource and is related to movements of resource (Kim et al. 2008). Figure 4.5 shows the structure of the product schema in the PPR^{+H} schema and an example of its application.

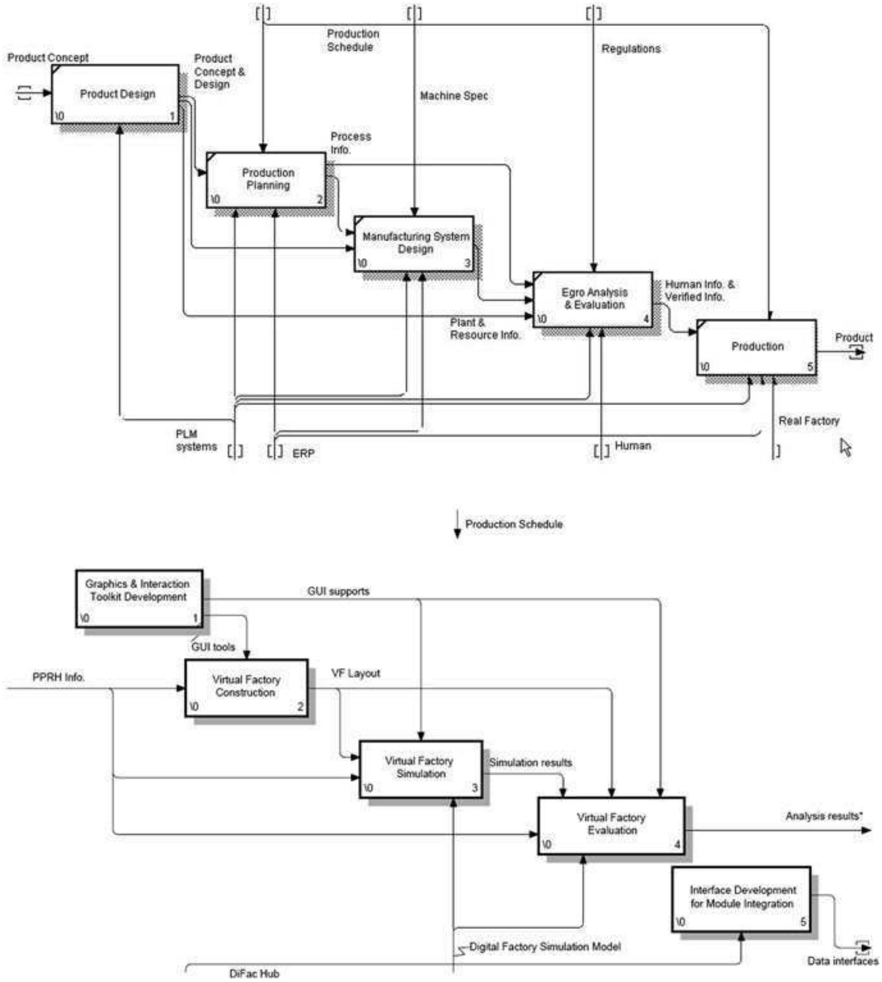

Fig. 4.2 A section of the workflow model of the engineering procedure using IDEF0 (Kim et al. 2008)

4.3.2 Process Schema

The process schema shown in Fig. 4.6 has "ChildWorkRelation" and "ParentWorkRelation" elements that are similar to those in the product schema. The process schema is able to represent a list of manufacturing processes and their detail works, such as operations and works. "PreviousWork" element represents a sequence in the process. It has an "ID" of the preceding process, and the process sequence can be defined by linked list algorithms. The "CyleTime" element

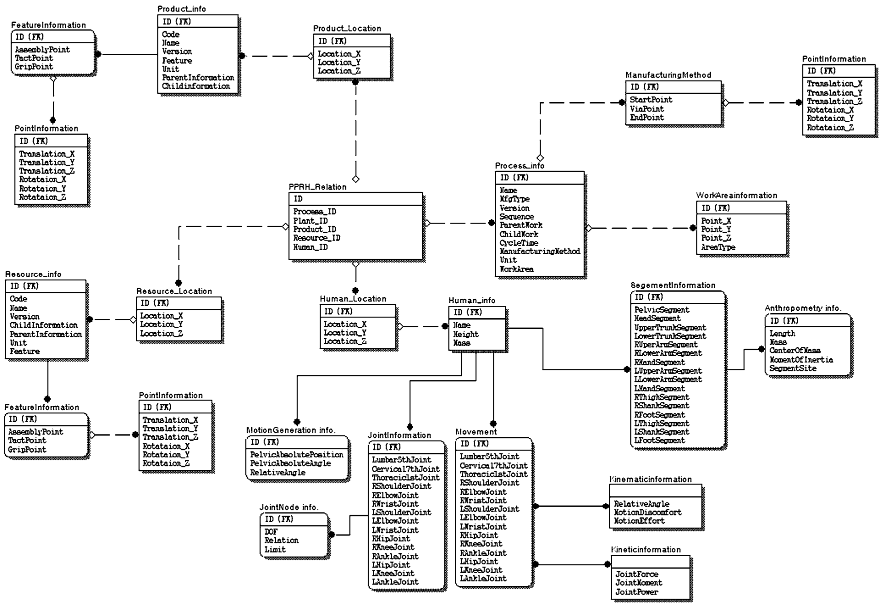

Fig. 4.3 A section of the information model of the engineering procedure using IDEF1X (Kim et al. 2008)

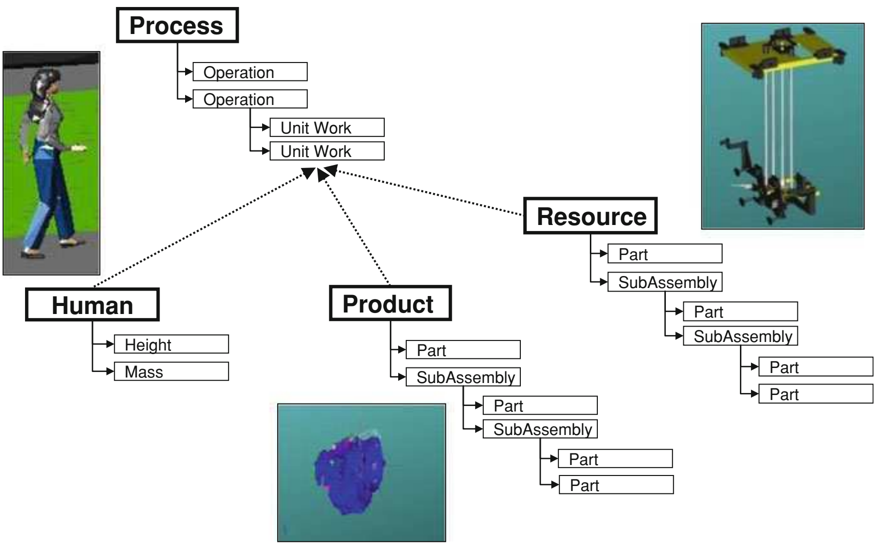

Fig. 4.4 The concept of PPR^{+H} schema for DiFac (Kim et al. 2008)

defines a processing time, and "WorkArea" includes information about the workstation by "AreaPoint" and "WorkStationName" elements. The "AreaPoint" element includes coordinate information to define the location of a workstation in

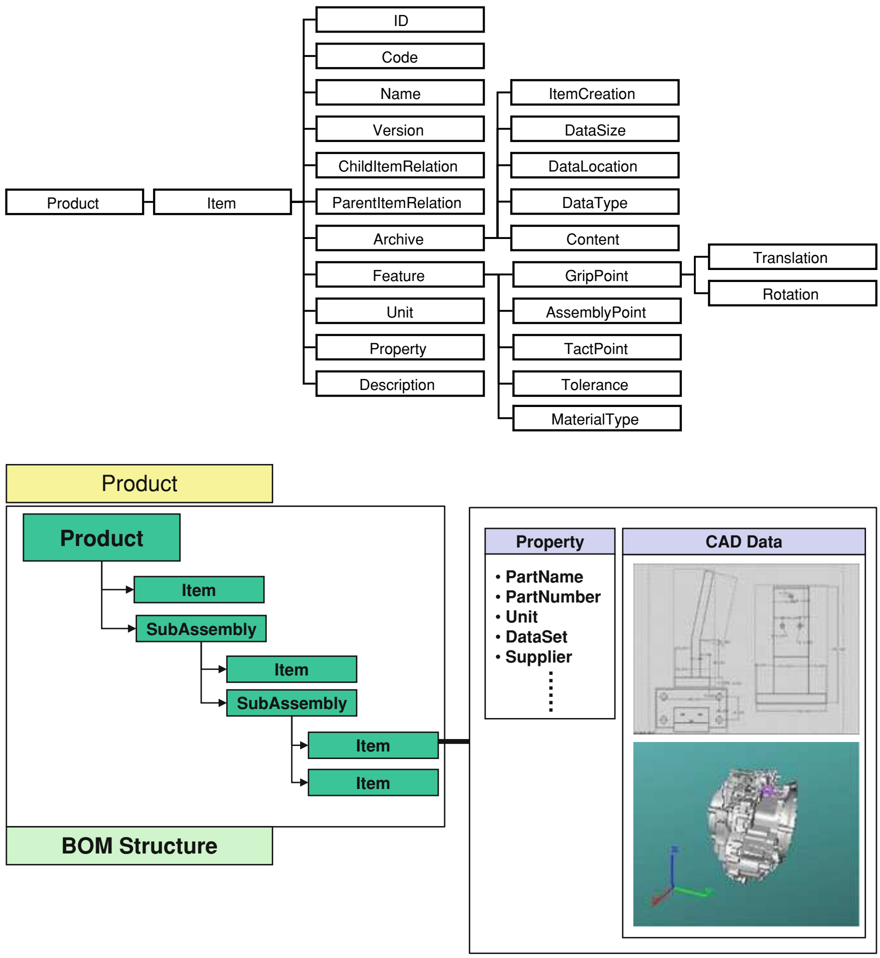

Fig. 4.5 Structure and an example of the product schema of PPR^{+H}

the factory layout. “ManufacturingMethod” has “StartPoint” and “EndPoint” properties and represents the path of a product through the assembly procedure. Also, “ViaPoint” property defines a detailed path (Kim et al. 2008).

4.3.3 Resource Schema

The resource schema is not only for machines and equipment but also for other objects in a factory, such as fences, columns, and walls. The structure of the resource schema is similar to that of the product schema, and it is hierarchically organized like a tree and its elements can have parent and/or child elements. The “Feature” element has “GripPoint”, “AssemblyPoint”, etc. The “GripPoint”

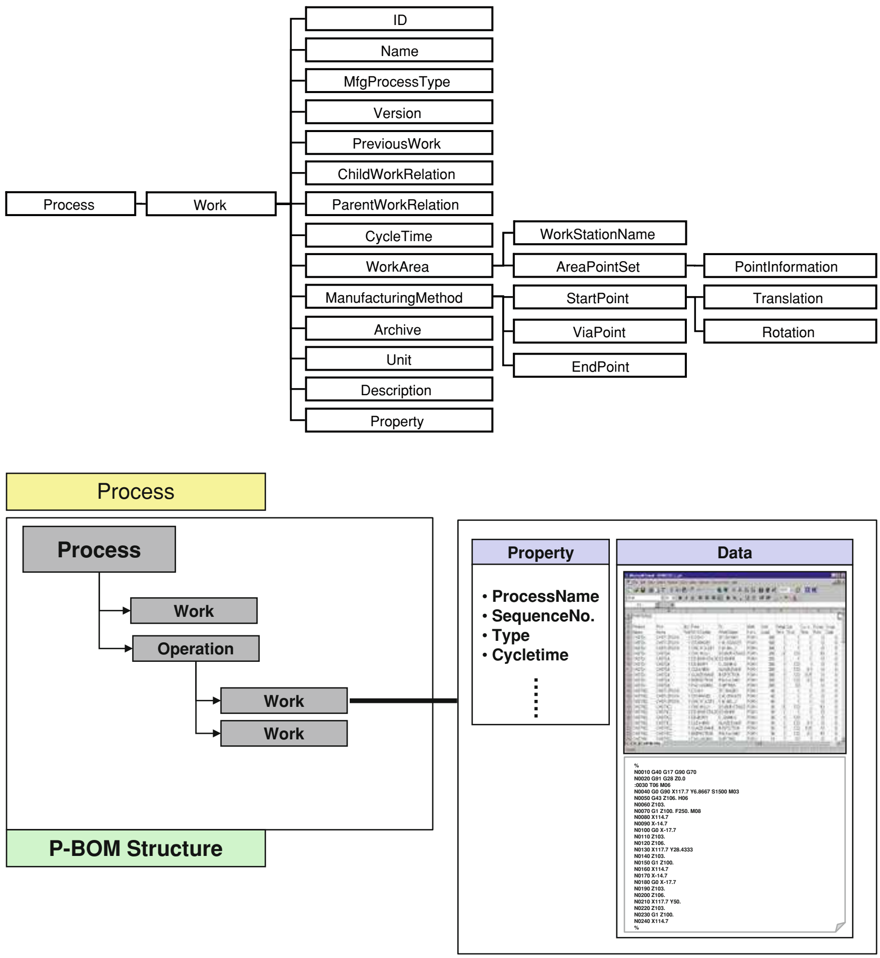

Fig. 4.6 Structure and an example of the process schema of PPR^{+H}

property is a gripping point for human hands, representing the point of contact (Kim et al. 2008). Figure 4.7 shows the structure of the resource schema in the PPR^{+H} schema.

4.3.4 Human Schema

Figure 4.8 shows the human schema of the PPR^{+H} schema. This schema is defined for the generation of anthropometric data of a human model. The anthropometric data in the human schema, such as segment length, mass, center of mass, and moment of inertia, are calculated by regression models using human height and

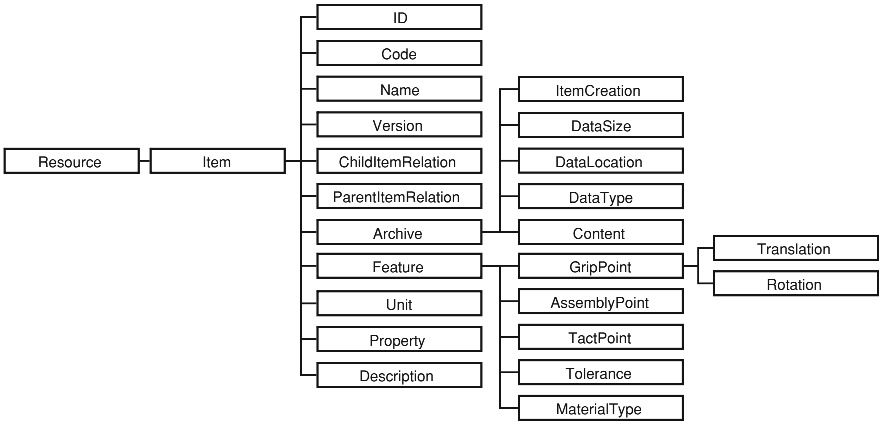

Fig. 4.7 Structure of the resource schema of PPR^{+H}

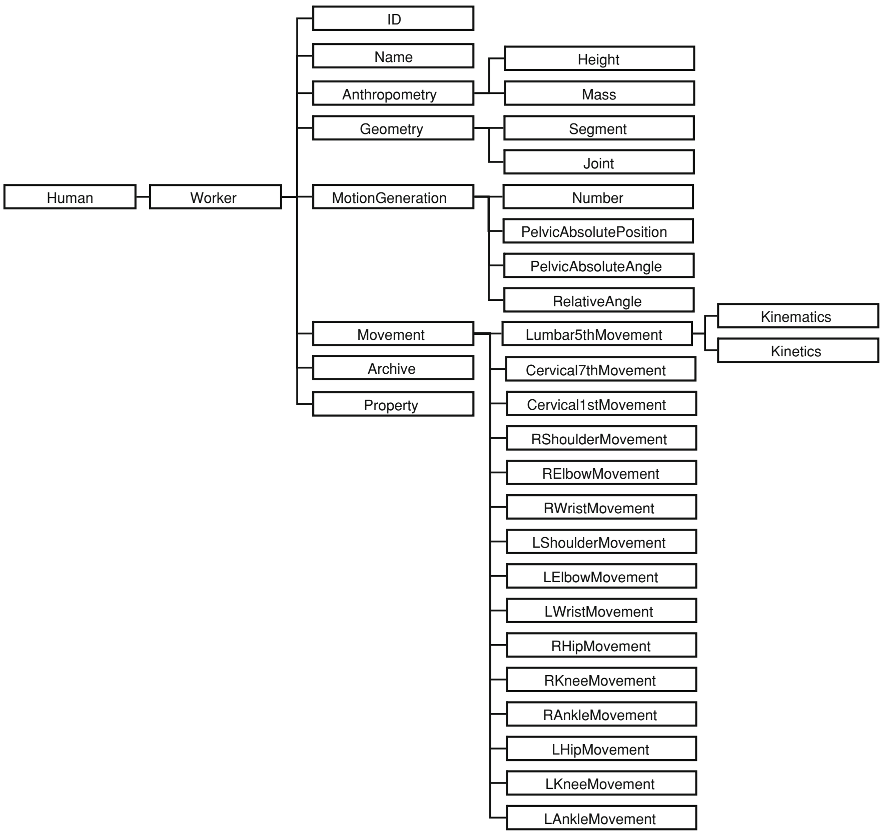

Fig. 4.8 Structure of the human schema of PPR^{+H}

mass properties (Shan and Bohn 2003; Rim et al. 2008). “Segment” properties are generated by human height and mass, and they are used to construct a human geometrical model with joint constraints. The “Geometry” and “MotionGeneration” elements are used for the animation of a worker in a 3D virtual environment. The “Geometry” element includes “Segment” and “Joint” properties to construct the human skeleton and joints. The “MotionGeneration” element has numbers, pelvis location, and rotation data on a global coordinate system, and we can use this information with the relative angles of each joint to animate a human character. The “Movement” element includes “Kinetic” and “Kinematic” properties for each joint; it can define a human movement and then present the analysis results of the human joint relative to motion, force, torque, and ergonomic evaluation results, such as rapid upper limb assessment, rapid entire body assessment, and Ovako working posture analysis system (Kim et al. 2008). As the human schema is used for other analyses also, it should be integrated with other models and information related to PPR from other digital factory applications.

4.3.5 PPRH Relation Schema

The PPRH relation schema is basically composed of the “Process” element, and the “Product”, “Resource,” and “Human” elements have their ID and location information. The “GRF” element includes an original coordinate point for all location information in each element. If we conduct a certain analysis, it is possible to define locations of products, resources, and human workers using the “GRF” and “Location” elements. Using the PPRH relation schema, we can make a cell, a workstation, and a line in digital factory by combination of PPR and Human elements. It can include physical models and related information along with logical information about the process (Kim et al. 2008). Figure 4.9 shows the PPRH relation schema of the PPR^{+H} schema. And, Fig. 4.10 shows parts of XML files based on the PPR^{+H} schema in case of an automotive general assembly shop (Kim et al. 2008).

4.4 PPR^{+H} Hub for DiFac Integration

To realize integrated management of all models and information related to PPR and human in a digital factory, a reliable and efficient enterprise-wide information management system is needed. In this section, we explain the PPR^{+H} hub for DiFac integration. It consists of a commercial PDM system, PPR^{+H} integrators, and web services that support data exchanges among diverse DiFac applications. The PPR^{+H} schema plays an important role for the exchange of PPR and human models and information. Using the PPR^{+H} hub, it is possible to apply digital factory models and information to engineering works and to manage all results of each engineering work.

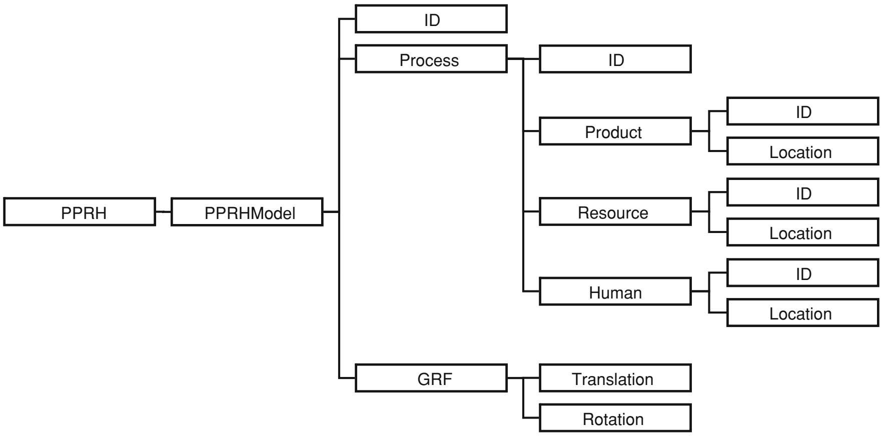

Fig. 4.9 Structure of the PPRH relation schema of PPR^{+H}

The PPR^{+H} hub is designed to integrate various digital factory applications and other enterprise-wide information systems which have digital factory models and information related to PPR and human. The PPR^{+H} integrator can handle XML files in PPR^{+H} schema using PPR and human information from diverse applications or legacy systems in a company. As shown in Fig. 4.1, there are three kinds of PPR^{+H} integrators, such as DiFac application adapter, XML adapter, and PLM adapter. The XML adapter manages XML files in the PPR^{+H} schema, and it is not necessary to modify the program until a common schema is changed. The DiFac application adapter and PLM adapter extract and store PPR and human information and models with XML files, and they should be developed individually for each application or PLM systems because each system has a different development environment and information representation method. Figure 4.11 shows an example of a PPR^{+H} hub implementation for DiFac. In this case, we use Teamcenter Engineering 8.0 by Siemens PLM software as a commercial PDM system and Microsoft IIS 5.0 as web services. PPR^{+H} integrator was implemented by means of MS Visual C++ 6.0 and Teamcenter API.

4.5 Conclusions

In this chapter, we presented integration framework and PPR^{+H} hub for DiFac. We defined the PPR^{+H} schema that provides standard XML files to create and manage models and information related to PPR and human in a digital factory. The PPR^{+H} hub consists of a commercial PDM system, PPR^{+H} integrators, and web services. The PPR^{+H} integrator is developed to exchange PPR and human models and information between the hub, DiFac applications, and other data management systems. The PPR^{+H} schema and the PPR^{+H} hub can not only reduce unnecessary

```
<<Item>
    <PId>000013</PId>
    <Name>Product</Name>
    <Version>A</Version>
    <ParentItemRelation>(null)</ParentItemRelation>
    <ChildItemRelation>
        <Id>S1</Id>
        <ChildItemId>000017</ChildItemId>
    </ChildItemRelation>
    <ChildItemRelation>
        <Id>S2</Id>
        <ChildItemId>000018</ChildItemId>
    </ChildItemRelation>
    <ChildItemRelation>
        <Id>S3</Id>
        <ChildItemId>000019</ChildItemId>
    </ChildItemRelation>
```


< Product >


```
<Work>
    <WId>000026</WId>
    <Name>UNITWORK</Name>
    <MfgProcessType>Assmbly</MfgProcessType>
    <Version>A</Version>
    <ParentWorkRelation>000023</ParentWorkRelation>
    <PreviousWork />
    <CycleTime>3.00</CycleTime>
    <WorkArea />
    <ManufacturingMethod>
        <StartPoint>
            <Id />
            <WTranslation>
                <WX>21294</WX>
                <WY>4050</WY>
                <WZ>290</WZ>
            </WTranslation>
```


< Process >


```
<RItem>
    <RId>000046</RId>
    <Name>DOOR_INSTALL_FRONT</Name>
    <Version>A</Version>
    <ParentItemRelation>000044</ParentItemRelation>
    <Feature>
        <TactPoint>
        <Id />
            <RTranslation>
                <RX>24450</RX>
                <RY>8410</RY>
                <RZ>1380</RZ>
            </RTranslation>
        </TactPoint>
        <TactPoint>
        <Id />
```


< Resource >


```
<Worker>
    <HId>000072</HId>
    <Name>LIM</Name>
    <Anthropometry>
        <Height>174</Height>
        <Mass>64</Mass>
    </Anthropometry>
<Movement>
    <Lumbar5thMovement>
        <Kinematics>
            <RelativeAngle>
                <x_Axis>-260.87</x_Axis>
                <y_Axis>109.12</y_Axis>
                <z_Axis>-111.68</z_Axis>
            </RelativeAngle>
        </Kinematics>
```


< Human >


```
<PPRHrealtion>
    <Process>
        <Id>000021</Id>
        <Product>
            <Id>000013</Id>
            <Translation>
                <X>0</X> <Y>0</Y> <Z>0</Z>
            </Translation>
            <Rotation>
                <X>0</X> <Y>0</Y> <Z>0</Z>
            </Rotation>
        </Product>
        <Resource>
            <Id>000050</Id>
            <Translation>
                <X>20827.12</X>
                <Y>2166.944</Y>
                <Z>3516.46</Z>
            </Translation>
            <Rotation>
                <X>0</X> <Y>0</Y> <Z>0</Z>
            </Rotation>
        </Resource>
        <Human>
            <Id>000072</Id>
            <Translation>
                <X>0</X> <Y>0</Y> <Z>0</Z>
            </Translation>
            <Rotation>
                <X>0</X> <Y>0</Y> <Z>0</Z>
            </Rotation>
        </Human>
    </Process>
    <GRF>
            <Translation>
                <X>0</RX> <Y>0</RY> <Z>0</RZ>
            </Translation>
            <Rotation>
                <X>0</RX> <Y>0</RY> <Z>0</RZ>
            </Rotation>
    </GRF>
```


< PPRH Relation >

Fig. 4.10 Examples of XML files based on the PPR^{+H} schema

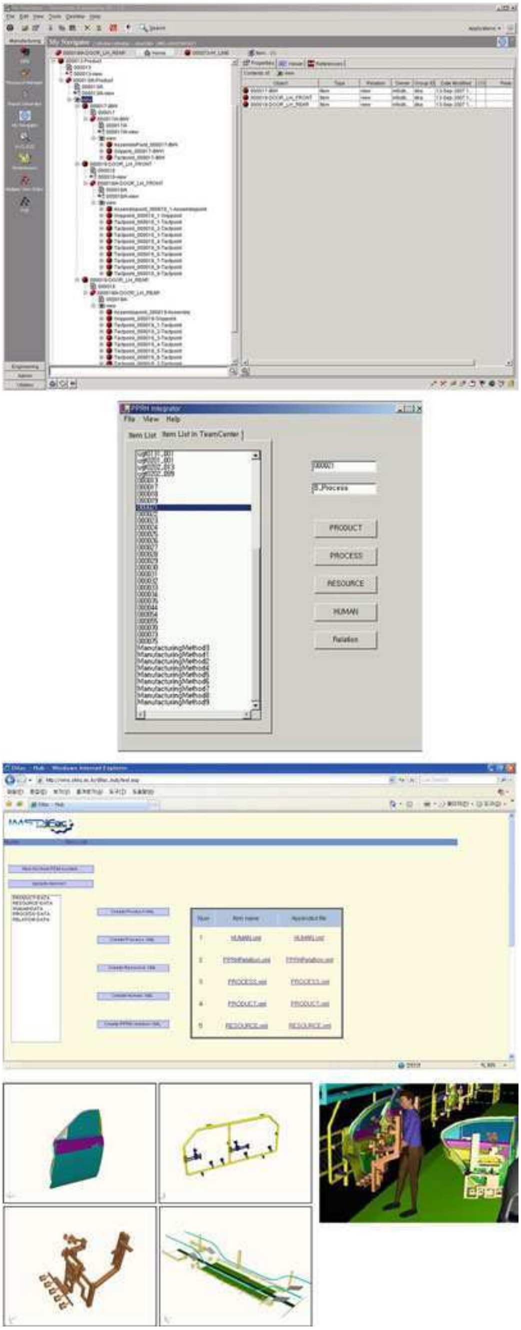

Fig. 4.11 Examples of PPR^{+H} hub implementation and DiFac applications (Kim et al. 2008; Rim et al. 2008)

effort in modeling a digital factory but also create a concurrent and collaborative environment in which users can share information and work together effectively.

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Chapter 5
RFID–ERP Key Data Integration Challenges

Luca Canetta, A. Salvadè, P. A. Schnegg, E. Müller and M. Lanini

Abstract This chapter provides an overview of the potential utilisation of RFID in the manufacturing context. More specifically the specificity of RFID applications, in terms of application fields, objectives, drivers, potential benefits, are analysed for various manufacturing strategies. The characteristics of the market context and of the structure of the manufacturing/assembly system having a significant impact on RFID application are identified and their influence described. An extensive review of industrial case studies classified according to the various manufacturing typologies (ETO, MTO, ATO, MTS, Retailing & Distribution) is provided. This allows to better assess the steps to be undertaken for developing a successful RFID applications, understand the activities to be included, identify the challenges, estimate the potential benefits and the required investments.

5.1 Introduction

The objectives of this chapter are providing an overview of radio frequency identification (RFID) applications in various production contexts and outlining all the management aspects to be taken into account for the RFID deployment:

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- *Objectives*: RFID can be applied for a multitude of different objectives, among them increasing efficiency, improving visibility, analysing processes for redesigning them, dynamically adjusting production system policies and parameters, applying sophisticated production planning and control strategies, and improving supply chain collaboration. Among others, the objectives vary according to the manufacturing typology, the application boundaries (inside a single company vs. supply chain), the field of application (product: structure, life cycle, and cost; assets: closed vs. open loop).
- *Level*: Technically speaking, an RFID infrastructure can be applied to almost everything, even if this can require completely different amount of investments. Thus, managerial considerations have to guide the choice of the item to tag (single products, case, pallet, movable assets, fixed assets, people, etc.). A similar approach has to be followed for specifying the number and position of RFID readers and antennas.
- *Potential benefits*: The established tagging objectives and level, along with the position in the supply chain for applications going beyond the single company boundaries, determine the potential benefits of the introduction of a given RFID architecture and strategy. The benefits are strongly influenced by the use that is done of the timely and reliable data provided by RFID. The direct benefits are constituted by the automation and by the removal of some tasks, and the indirect benefits are linked to the improvement of management strategies. Indirect benefits can be more significant than direct ones, but their achievement requires the deployment of more complex and challenging strategies.
- "*Investments*": A widening of the scope (number of involved processes/products/locations) of RFID application and of the extent of modification of current practices usually also corresponds to the increase of the required investments, because of a greater complexity of the RFID infrastructure as well as to the necessity of tightly coupling it with various company information systems (or even to deploy new information system functionalities).
- *Potential barriers*: Technological and organisation/management barriers have to be considered while defining an RFID infrastructure and its use at strategic level. Technological barriers, mainly linked to the physical context (distance, number, and speed of readings; interferences: metal, liquid, etc.) in which the RFID infrastructure has to be deployed, are not extensively analysed here because of our focus on management aspects and to the existence in literature of many comprehensive guidelines explaining the most important technological requirements. Organisational and management barriers arise from the necessity to efficiently use the data provided by RFID, this implies more dynamic decision processes and can lead to workshop workforce empowerment with consequent potential resistances from middle management. Suitable rules, procedures, and tools (software) have to be defined and implemented for overcoming all potential barriers.

5.2 Background

Introducing RFID allows to automatically track and trace items, the latter can be raw materials, semi-manufactured product, or finished goods.

5.2.1 Track

The ability to physically locate the specific location of articles or items inside a facility or to identify articles or items used to fulfil an outbound sales order (e.g., where it is and when it arrived there). The possibility to know almost in real time the location of a specific item reduces the uncertainty in the supply chain allowing to better align physical and information flows.

5.2.2 Trace

The ability to search historical records identifying manufacturing processes, the source of ingredients or components, etc. (e.g., how it was processed and what was done). Traceability data improve internal business process enabling the implementation of lean manufacturing concepts. Tracing techniques can be used to detect system status, analyse system performance, and support decision making.

Reliable RFID tracing and tracking systems can improve supply chain performances in several ways; thus, a clear strategic vision of the objectives of RFID introduction is mandatory to deploy the most suitable RFID infrastructure, considering both the hardware and the software level (middleware, ERP integration, etc.). The characteristics of the physical environment as well as those of the applied manufacturing typology can have a strong influence on the choice of the most suitable RFID introduction strategy.

In the following sections, various manufacturing typologies are briefly described to explain the factors and the processes that should be taken into account while developing an RFID strategy.

For instance, depending on the type of manufacturing typology, the main focus can be related to:

- Supply chain visibility to improve forecasting quality
- Inventory-level monitoring to avoid stockout
- Resources use monitoring to identify bottleneck and increase plant productivity
- Single-item product life cycle management to efficiently manage reuse, recycle, and disposal
- Production lot tracking to facilitate return handling of product potentially containing suspect components/materials
- Distribution lots tracking to improve customer service level and reduce the frequency of reconciliation issues.

5.3 Manufacturing Typologies

The manufacturing typologies are defined according to the position of the order penetration point (OPP). The OPP is traditionally defined as the point in the manufacturing value chain for a product, where the product starts to be linked to a specific customer order. For this reason, sometimes the OPP is called the customer order decoupling point to highlight how this point divides the manufacturing stages that are forecast-driven from those that are customer-order-driven.

According to the "Supply Chain and Logistics glossary", the various manufacturing strategies can be classified, in terms of increasing number of stages that are customer-order-driven, in the following way (http://cscmp.org/Downloads/Public/Resources/glossary03.pdf):

- *Make-to-stock (MTS)*: A manufacturing process strategy where finished product is continually held in plant or warehouse inventory to fulfil expected incoming orders or released based on a forecast.
- *Assemble-to-order (ATO)*: A production environment where a good can be assembled after receipt of a customer's order. The key components (bulk, semi-finished, intermediate, subassembly, fabricated, purchased, packing, and so on) used in the assembly or finishing process are planned and usually stocked in anticipation of a customer order. Receipt of an order initiates assembly of the customised product. This strategy is useful when a large number of end products (based on the selection of options and accessories) can be assembled from common components.
- *Make-to-order (MTO)*: A manufacturing process strategy where the trigger to begin the manufacture of a product is an actual customer order rather than a market forecast. For MTO products, all necessary design and process documentation is available at time of order receipt.
- *Engineer-to-order (ETO)*: A process in which the manufacturing organisation must first prepare (engineer) significant product or process documentation before manufacture may begin.

Each manufacturing typology is suitable for a specific market and production environment. In the following subsections, the impact of these characteristics is analysed deeper in detail to develop a methodology allowing to determine for a specific company which are the priorities, the requirements, and the RFID level of application.

5.3.1 Delivery Lead Time Requirements

As can easily be understood looking at the definition of the OPP, this is the primary criteria influencing the manufacturing typology. In fact as the customer acceptable delivery lead time becomes shorter, the probability that at least some of the production stages should be undertaken on the basis of forecast increases.

The delivery lead time is usually close to zero for the majority of consumer products that are thus managed according to an MTS policy. On the other hand, as the customisation level increases, the customers are willing to wait more to receive a product that better fits their wishes (expressed through a customer order). This allows to adopt a manufacturing typology for which at least some of the manufacturing stages are not forecast-driven.

5.3.2 Customer Involvement (Customisation Level)

Customer willing to wait is determined by the customer involvement in the definition of the characteristics of the finished product. The greater is the customisation level, the greater is the number of step that can be easily undertaken only after the reception of the customer order. In the case of ETO products, the customer usually starts defining the product requirements (specifications) and then closely interacts with the supplier till an agreement about the final design is reached. In this case, being uncertain the results of the co-operative design, the purchasing and manufacturing tasks should not begin till the agreement.

The customisation level has a direct impact on product diversity, the latter hinders the possibility to adopt MTS approaches (even if a redesign is not necessary) because keeping in stock enough units of each potential finished product configuration results in immense final goods inventory.

5.3.3 Demand Volatility

Limited demand volatility, which can be measured calculating the demand standard deviation, is a prerequisite to apply forecast-driven manufacturing typologies, such as MTS and ATO. The increase of the customisation level is usually followed by an increase of demand volatility. The level (finished goods, modules, and components) at which the volatility can be reduced determines the forecast-driven approach to be followed.

5.3.4 Product Volume

Product volume has an effect on demand volatility; in fact, given the same volatility (standard deviation), the relative variability (coefficient of variation) is lower for high-volume items (having a greater average demand). Thus, it is easier to apply forecast-driven methods to high-volume items. As product volume increases, the manufacturing and assembly system structure is also modified, becoming more and more product oriented (flow shop).

It should also be remarked that a relative low-demand volatility and a high average demand rate are necessary conditions to the application of just-in-time (JIT) production planning and control methods.

5.3.5 Production Complexity

The production complexity is linked to the breadth (the average number of items per bill of materials—BOM level) and depth (the number of BOM levels) of the product structure. A deep product structure may easily result in long cumulative production lead times as well as complex production routings.

The BOM breadth is one of the elements describing the product customisation level; however, an overall analysis of the BOM profile is needed to understand which production stages/components can be managed on the basis of forecast.

5.3.6 Bill of Materials Profile

The BOM profiles, usually specified using capital letters, describe the number of items present at the BOM top level (end products), middle point (subassemblies and/or fabricated parts), and bottom level (raw materials and/or purchased components):

- V profile indicates a divergent material flow where from a few raw materials, a large number of finished products is created (chemicals and pharmaceutical).
- A and T profiles typically indicate the presence of assembly phases. On one hand, A profile represents a traditional assembly where parts are progressively assembled together across a product structure with many levels. On the other hand, T profile well describes the concept of postponement, where a wide variety of finished goods is obtained from a narrow set of predefined modules.
- X profile also describes typical modular product design, it can be considered as a combination of an A profile (raw materials—modules) with a V profile (modules—finished goods).

The possibility to define components or modules common to a high number of finished goods increases component forecast reliability and results in a smoother average demand; thus, allowing the application of a wider spectrum of manufacturing typologies and production planning and control methods.

5.4 Structure of the Manufacturing and Assembly System

The RFID use is also influenced by the internal structure of the manufacturing and assembly system, in other words, the manner in which the process flow structure is organised. The suitable structure is influenced by:

- Material flow complexity: the number of possible sequences of activities
- Process flexibility: the degree of independence of process performance and costs from product mix changes
- The number of different products to be produced as well as their production volume
- The level of capital investments and of labour content (and skills), influencing the repartition between fixed and variable unit cost.

5.4.1 Dedicated Flow Lines (Product-Oriented)

In this case, a limited number of products, each of them having a large production volume, follow a more or less common routing. These systems are very capital intensive and usually the applied workstations are designed to optimise the efficiency of the processes for a specific product family at the expense of their flexibility.

5.4.2 Job Shop (Process-Oriented)

Job shops are designed for producing many different items that are usually manufactured in small quantities. Thus, a wide variety of processes has to be performed on these workstations, according to an even greater number of routings. In this case, for each process, one or more universal machines are provided and arranged in a functional layout, mainly process-oriented. Job shop requires a high flexibility; this implies among others a significant presence of labour content that also increases the variable unit cost.

5.4.3 On Site Manufacturing (Project)

In this case, there is no product flow because the required equipments and inputs should be brought to the project location. A project usually concerns the realisation of an extremely complex product, implying a greater extent of engineering and process-planning work compared to job shop and flow manufacturing. As a consequence, the labour impact is extremely high; furthermore, the level of required skills is also particularly high. Thus, the variable cost for project is very high. Usually, the production is undertaken at the unitary lot level, for this reason, a high flexibility is required.

5.5 Capacity-Oriented and Material-Oriented Manufacturing Systems

Finally, the orientation of the manufacturing system should be analysed in terms of added value entity and sources. Material-oriented manufacturing relies on the final assembly of many purchased components and subassemblies, resulting in a limited added value coupled to a significant importance and criticality of inventory management. On the other hand, capacity-oriented manufacturing is characterised by complex and capital intensive processes that transform a few basic materials into a great variety of finished products, thus providing a substantial added value.

5.6 RFID Potential Application in Supply Chain Management

Several supply chain processes can be affected by RFID introduction. In this section, a description of the potential use is provided to easily analyse the specificities of the strategies to be applied according to the adopted manufacturing typology as well as to the structure and orientation of the manufacturing systems.

5.6.1 Items to Tag

The current cost of tags as well as some privacy issues hinders the massive application of tag at the single-item level. However, despite the previous remark and the significant expected benefits in terms of supply chain management improvement of pallet and case tagging in the retail industry and distribution activities nowadays, it seems that RFID tags are especially used as the single-item level for some category of expensive products (apparel and books). For instance, their use allows to better manage off-the-shelves stocks, thus reducing stockout. This improves customer service and increases revenue, because of the reduction of lost sales. Anti-counterfeiting initiatives in luxury and pharmaceutics domains as well as the more stringent regulations about food and drug safety based on traceability requirements (Food and Drug Administration Prescription Drug Marketing Act—Pedigree Requirements) are also pushing RFID use at the item level.

Supply chain–based RFID applications are both discouraged by technical problems, such as unsatisfying lecture rate especially for cases (GENCO application in warehouse management shows a pallet read rate 96% but a case read rate 60%) and by the lack of established practices for cost and benefits sharing among the different supply chain actors (Chow et al. 2006). The growth of RFID application for supply chain management at pallet and case level will be spurred on by the development of new business models fostering collaboration and made possible by the analysis of the data collected through the RFID infrastructure. Mere replacement of barcode by RFID, not providing sufficient return of investment, usually does not justify the deployment of a RFID architecture (Dighero et al. 2005).

The use of RFID for movable asset management proves to be profitable, as shown for instance by the applications made by Scottish Courage (aluminium beer kegs), Volkswagen (special racks for car body parts transportation), and Migros (refrigerated trucks) (see Lampe et al. 2006). These successes are explained by the possibility to work on closed loop, tagging a limited number of reusable assets having high value (both in monetary terms and considering production efficiency consequences), a long life cycle, and a huge number of uses (reducing the amount of tag purchasing cost).

The high value and the long life cycle coupled with the inner product complexity and the necessity to ensure extremely high level of safety and functional requirements also explain the use of RFID at the single-item level in specific sectors, both for finished products and some critical components/subassemblies. This is the case in the aviation sector, where airplanes manufacturers are planning to introduce RFID to facilitate maintenance operations and increase their reliability.

The latter application shows as RFID can provide a valid contribution not only for managing the huge material flows characterising consumer packaged goods companies but also to companies realising a few complex units according to an ATO policy. In this case, RFID contributions are mainly related to project management facilitation (construction companies), to the reduction of errors linked to the use of the wrong customised components, and to the support of the various life cycle activities (maintenance, reuse, recycle, and disposal).

5.6.2 Tagging Objectives

The data collected, thanks to RFID tags, can be used for many different objectives related to a multitude of processes, spamming the entire product life cycle (from design to disposal). The focus of RFID introduction is clearly influenced by the company's manufacturing environment (manufacturing typology, manufacturing system structure, added value source, and relevance), which should be carefully taken into account while establishing the company strategy.

The traceability and tracking ability of RFID technology can be used to modify various processes at different extent. A first category of basic applications, which neither require complex data filtering and analysis nor the development of new business models and information-sharing approaches, is simply the enhancement of traditional processes previously undertaken using less performing automatic identification technologies, such as barcode. The following processes belong to this category:

- The inventory-shrinkage reduction made possible by automatic tracking
- The customer service improvement because of human error reduction (automatic data capture and verification) and to automatic off-the-shelves inventory-level updating
- The lead time, and the parallel labour cost, reduction because of the simplification and/or the automation of various tasks related to receiving, picking, shipping, and warehousing activities.
- The support to suspect/defective product recall and to the gathering and retrieving of the information needed to be compliant with product safety regulations (traceability)
- The enhancement of the efficacy of anti-counterfeiting activities and of them for fighting against parallel sales

Even without the establishment of new approaches, the availability and sharing of more reliable and detailed information contribute to solve several potential supplier–customer misconceptions; for instance, Intel and its customer (a notebook OEM) understand how the recourse by the latter to costly rush orders is often unnecessary. In fact, because of various inefficiencies, identified through the analysis of RFID data, the delay from the rush order shipment from Intel to the component use by the customer accounts for more than 1 day even if the two facilities are a half an hour apart (Dighero et al. 2005).

Another series of more pervasive RFID applications requires the development of a comprehensive strategy for information gathering, analysis, and sharing as well as the reengineering of some traditional supply chain processes. The improvement of supply chain visibility, because of the possibility to know both the inventory level of the supply chain partners and the customer demand at retail stores, implies an enhancement of forecasting accuracy and demand management efficacy. However, this requires the establishment of a formalised approach for data mining, aggregation, and sharing, which provide updated valuable information to the various supply chain partners without submerging their information systems with the continuous flow of raw data stemming from RFID tags reading. The achieved demand uncertainty reduction also reduces the bull-whip effect and allows to:

- Decrease the entity of the safety stocks
- Modify the parameters of stock replenishment methods, decreasing the average stock
- Replace stock replenishment and MRP methods with other production planning and control approaches inspired to JIT philosophy
- Improve customer relation management through the analysis of the automatically generated database about final customer behaviour and preferences
- Develop new collaborative (win–win) strategies among the supply chain partners shifting the focus from local to global performance optimisation

The use of RFID also allows to modify maintenance planning and product/resource life cycle management, obtaining greater efficiency at the expense of initial efforts devoted to change management and practices.

Extended use of preventive maintenance and improvement of its efficacy: Thanks to the reliable information about the historical use of a given product (resource) the planned preventive maintenance can be managed according to the real use of each single item and not according to average maintenance intervals that cannot take into account the specificity of the activities linked to each single item. This allows to better plan the maintenance interventions, avoiding breakdowns (because of products undergoing during the average maintenance interval a workload significantly greater than the average one used to estimate the maintenance interval) and simultaneously increasing the operational life of each items (recognising which products will undergo during the average maintenance interval a workload significantly lower than the average one and thus do not need any maintenance).

A similar approach can be followed for product (resource) life cycle management; this is especially interesting for really expensive and complex products having a long life cycle, such as in the aircraft-manufacturing sector where it can be of approximately 30 years. The reuse, recycle, and disposal of aircraft components are very complex because of the stringent regulation concerning human security and safety as well as the huge number of actors, furthermore distributed all around the world, involved in the tasks undergone by this components (inspection, programmed maintenance, repair, substitution, etc.). The efficacy deployment of RFID in this kind of sectors will take quite a long time and requires the development of an infrastructure capable of working with the standards used in different regions of the world and to ensure a secured access, update, and backup of all the gathered sensible data. Furthermore, technical aspects still require further research and development because it is necessary to design and develop "permanent tags", following a component through its entire life cycle and being able to deal with various critical physical environment conditions. Finally, it should also be remarked that the recourse to RFID combined with other techniques can help to fight against airplane parts counterfeiting, which is a major problem for airlines, maintenance companies, parts suppliers, and the flying public.

The information collected through the RFID infrastructure also plays an important role in production resources management. First of all, the increased supply chain visibility allows to better synchronise the production planning across the various supply chain actors, simultaneously improving the resource (capacity) use for each actor and the flexibility of the entire supply chain (Measured for instance by its response time: The time it takes the integrated supply chain to respond to abnormal and significant change in demand, calculated as the sum of order fulfilment lead time and source cycle time). The continuously updated information also allows to easily identify the bottlenecks and to analyse how they shift according to product mix and volume. Another use of this kind of data is the calculation of the cycle time, which includes both processing and waiting time, for a specific item/lot undertaking a specific process. The latter can be used to estimate and/or to modify the cost price as well as to modify the parameterisation of the ERP system, which usually is not managed in a dynamic way and thus results to be not aligned with the shop floor reality. Furthermore, the repartition of cycle time between waiting and processing time can be analysed to identify if the dispatching and production planning and control rules should be modified to improve company performances.

The analysis and improvement of capacity use continue to increase in the future because of the shift, among others facilitated by the use of RFID, from forecast-driven activities to demand-driven activities. The latter implies that for an increasing number of processes, managed according to pull philosophy inspired to JIT concepts, the focus will be on capacity flexibility instead of on inventory flexibility, as required by push manufacturing.

5.6.3 Potential Benefits

Recently, various authors investigated the potential benefits of RFID applications in supply chain management (Li and Visich 2006; Maloni and DeWolf 2006; Tajima 2007; Lu et al. 2006; Smith 2005; Bendavil et al. 2007) and underlined how companies in different positions in the supply chain can reap different benefits by RFID introduction. A first class of generic benefits can apply to all the supply chain actors, even if their impact can be different from one actor to another. Among them, some of the most publicised benefits are:

- Shrinkage reduction (theft, spoilage, administrative error, and product misplacement prevention)
- Material-handling activities labour cost reduction
- Data accuracy enhancement and transaction error reduction
- Exception management
- Improved information sharing and data visibility (Collaborative Planning Forecasting and Replenishment (CPFR), vendor-managed inventory, etc.)

Analysing deeper in detail the benefit for manufacturers and suppliers, thus of all actors involved in production and assembly activities, the main benefits arise from:

- Real-time production tracking (work in process (WIP), components, and finished goods)
- Quality control (product recall, avoidance of wrong operation/assembly sequences)
- Supply and production continuity (preventive condition-based maintenance, movable/reusable asset tracking, production planning, precise estimation of time and workflow for a specific item/lot, reduction of production disruptions, and rescheduling activities)

Looking at distributors and more in general at logistics providers, the main advantages stem from the possibility to optimise asset and space use:

- More flexible product allocation (easier identification of each specific lot wherever it is stored)

- Automation of many material-handling tasks and elimination of redundant manual-checking activities
- Efficient use of reusable asset, improved shipment consolidation, and route planning

Focusing on retailer benefits also the performance measures related to consumer services assume a significant importance:

- Stockout reduction (real time updating of off-the-shelf and backroom stock level, automatic replenishment)
- Customer service improvement (increase staff availability for customer assistance, enhanced marketing and customisation practices, tracking product delivery status, and improved availability)
- After sales services facilitation (defective product recall, warranty and maintenance activities management)
- Inventory-level reduction (improved stock-level visibility + enhanced model of the customer demand + decrease of demand and inventory-level uncertainty = decrease of safety stock + decrease of replenishment parameters + applicability of new inventory management approaches)
- Yield management (price customisation, promotions, and discounts).

5.7 Case Studies of RFID Application for Various Manufacturing Typologies

The following section describes various RFID applications classified according to the manufacturing typology to which the company belongs. For each case study, the impact of the above-described aspects will be pointed out to demonstrate their effect in real life applications and to better understand how the RFID strategy should conform to the company environment requirements. Usually, the typical RFID applications are not dictated by technology feasibility constraints but by cost-opportunity reason, in other words, some RFID applications are feasible but not profitable depending on the challenges posed by the manufacturing typology.

For instance, RFID application in sourcing activities is unlikely to provide significant value to most manufacturers who receive from their suppliers a limited variety of products in large quantities. In fact, for these manufacturers, the receiving and storage processes are relatively simple, thus the enhancements provided by RFID are valueless because they do not allow significant money saving.

5.7.1 RFID Application in ETO Manufacturing

ETO products manufacturing is completely managed on the basis of the real customer demand, furthermore in the first step, the final design of the product is not established yet and results from the analysis of the specific customer requirements. Finally, the high level of customisation and complexity usually implies long production and delivery lead time along with some changes to the original design can be required.

In this situation, the accent is put on the efficient management of the production asset and a formal and performing project management, aimed at synchronising as much as possible with the different processes and to ensure at the same time both a high level of use of the key resources and their availability at the correct point of time.

RFID have been already applied in ETO manufacturing for asset management (maintenance and more generally, middle-of-life management), project management (asset localisation, verification of the respect of the project/activity time schedule against the baseline plan), operation support (readily available data about the identity of each highly customised ETO and about its specificities related to quality control inspection results, material-handling and installation instruction, etc.), recycle and disposal (end-of-life management).

5.7.1.1 Asset and ETO Components Identification and Localisation

RFID tags can be permanently attached to capital equipment and fixed assets, including pallets, RPCs, cylinders, lift trucks, tools, vehicles, trailers, and equipment. Fixed position readers placed at strategic points within the facility can automatically track the movement and location of tagged assets with 100% accuracy. This information can be used to quickly locate expensive tools or equipment when workers need them, eliminating labour-wasting manual searches. This is particularly important in the ETO contest where, considering that all the processes are managed according to pull philosophy inspired to JIT concepts, the focus is mainly concentrated on capacity, flexibility, and availability (Goodrum et al. 2006).

The nature of ETO manufacturing where every time the manufacturing takes place at a different construction site increases the difficulty to collect and efficiently share all the relevant information. In fact, construction sites represent dynamic, where components are frequently moved, and uncontrolled, where nor components locations neither moving routings/routes are predetermined and formally defined, environments. This requires to rely more heavily than for the other manufacturing typologies on active tags (ensuring long reading ranges and reducing the transmission problems encountered in presence of metals and concrete) and on mobile readers (often installed on material-handling equipment or provided in the form of pocket PC to operators).

The temporary nature of construction supply chains as well as the high number and degree of heterogeneity of the participating organisations as well as the long life cycle of the ETO components require the collection of a great quantity of information of different nature and form that should be easily accessible to all the involved organisations. This suggests the recourse to a distributed and decentralised data structure, one option is to stock locally into the tag the information that are required by the day-by-day activities of people working on the construction site (the recourse to active tag allows to dispose to more memory for the information upload and ensure good read/write capabilities), on the other hand the tag is only used to store the unique ID and the data stored in one or more databases can be retrieved through the use of the unique ID (the latter requires the establishment of a good data infrastructure composed by a reliable and robust wireless LAN and by database systems able to respond in a timely manner to the queries and to the information updates).

5.7.1.2 Asset Management

RFID also allows to collect reliable data about the use of expensive capital equipment and consequently to implement improved preventive maintenance programs based on specific asset use rate. As a result, many hidden maintenance costs, such as production losses because of downtime, cost for maintenance equipment, storage room for maintenance equipment, and an increased maintenance workforce can be reduced. This can represent significant savings considering that for some engineering industries, maintenance costs represent a high share of the total costs (for instance, 30–50% for mining). This kind of applications can require to also couple sensors (temperature, pressure, humidity, etc.) to RFID, thus for this kind of sophisticated implementations, tag cost is not a critical point because of the high value of the tagged object, its reusable nature, and the capabilities required to the tag (long reading range, read/write capabilities, integration with sensors, and local data storage) (Boër et al. 2010).

5.7.1.3 Project Management

The assessment of the completed construction percentage can be strongly simplified relying on RFID. Even more attractive seem RFID applications that do not only cover the construction phase but also deploy their effects throughout the whole service life of a building/plant. Real-time materials and asset tracking not only facilitates logistics task, with the drivers being informed when approaching the construction site where the material should delivered, but also allows to immediately detect any discrepancy and communicate them to all the involved actors. Thus, the site engineer can reschedule the activities on the basis of the constraints related to materials and asset availability as well as delay/anticipate future material deliveries on the basis of the real project process (without further decreasing productivity-engaging resources in useless activities and/or obliging them to evolve in a crowded and disorganised work environment) (Ghanem and AbdelRazig 2006).

Tagging critical customised ETO components reduces the impact of human subjective interpretation of information and instructions; in fact, the state of each component (needs for quality inspection, quality inspection results) is known in real time as well as the detailed instruction for its use thus reducing costly misuse mistakes (the latter can be particularly critical in an ETO environment where product complexity and regulations about security and functional components require to ensure the absolute quality of the "finished product", such as for instance the case for nuclear plant construction).

5.7.1.4 Life Cycle Management

RFID can also be used to improve the life cycle management of some components of an ETO; for instance, they can help the middle-of-life management of those requiring periodic control and maintenance and for which the historical information should be easily accessed on site (fire valves). The tagged elements can also be better recycled and reused while protecting the operators assigned to this tasks that can known exactly which are the potential risks as well as the procedures and cautions to be applied (Ergen et al. 2007).

5.7.1.5 People Management and Safety

The possibility to knowing in real time the position of each worker in such wide, dynamic, and uncontrolled work environment improves workforce safety, thus pushing the use of RFID to human localisation and to restrain access to dangerous sites. The investments made for ensuring workforce safety can then also leveraged to improve workforce productivity; for instance, assigning a specific task to the worker having the required competences who is closer to point of execution. However, such kind of RFID use aimed at productivity improvement should be carefully planned and preliminary presented to the workforce for asking their approval because they can raise problems related to privacy violations.

5.7.2 RFID Application in MTO Manufacturing

MTO products are associated to process-oriented job shops, where several different finished products are simultaneously produced using the same resources (but according to different activity sequences, for undertaking various treatment characterised by different specifications). The usual complexity of BOM and manufacturing procedures in MTO increases the difficulty to fulfil all the orders on time. This requires to efficiently monitor and manage the production system, which for MTO is the key factor to ensure customer satisfaction (considering the absence of stocks of finished products), to:

- Reduce the number of rejects and production mistakes
- Timely react to production problems and reschedule production order priorities

- Improve workload balance
- Identify bottlenecks and remove them
- Increase production resources availability

According to the objectives stated above, RFID applications are aimed at maximising the correct use of the production resources to increase customer satisfaction and reduce costs, thus asset management keeps its importance while components and products identification, both at the item and at the batch level, becomes more and more relevant.

5.7.2.1 Asset Management

RFID, as was the case for ETO, can be used to develop more efficient preventive maintenance programs, based on effective resource use. However, usually in a shop floor, various resources capable of accomplishing a specific task exist, rendering less significant the contribution of RFID to company wealth. Reusable asset management using RFID keeps its importance for MTO because in a shop floor, a series of movable reusable asset has to be used to move components and subassemblies from one station to another. The unavailability of such movable asset can provoke resource famine, in other words, resource idle time because of an entry empty queue, which has consequences on lead time, WIP, etc.

5.7.2.2 Production Planning

In many enterprises, the unsatisfying efficiency of production-planning management undertaken through the ERP system can be explained with the impossibility to receive detailed and updated information from the shop floor. Similarly, the production planning elaborated by the ERP is neither easily transformed in clear instructions for the operators nor timely transmitted to them. The above-presented difficulties reduce production efficiency because they provoke the separation of information flow and materials flow at the shop floor level.

In day-by-day management, RFID application allows event-driven planning and manufacturing, thus the direct and in “real-time” modification of production scheduling in function of demand and production environment (breakdowns, early/late delivery from supplier, scraps, quality problems with suppliers, etc.) modifications. Moreover, the data collected trough RFID can be used to assess the performance of the production system and of the implemented production planning. In fact, reliable statistics about production resources use, lead times, WIP levels can be computed at a high frequency and being associated to the market environment (product mix, demand volume, demand volatility, production order size, etc.). The latter allows to identify the bottlenecks, to investigate the reasons of the workload imbalance they generate, and thus to implement corrective actions on the basis of a realistic shop floor modelling. Finally, the information collected through RFID at the shop floor level should be moved upwards into the ERP system to modify the value of the parameters used to generate the production planning. For instance, using RFID allows to automatically update the value of working time, setup time, workload, idle time, etc. All these values are used in an ERP system for a multitude of objectives, such as the calculation of the cost price and that of the order quantity.

The propagation of the information collected using RFID outside the boundaries of the single company allows to refine at the same time the production planning of the various supply chain actors as well as to automate some tasks, such as components and raw materials automatic replenishment and vendor-managed inventory.

5.7.2.3 Quality Improvement (Mistakes Prevention)

In a dynamic and unstructured environment, where various products (having complex BOM) share simultaneously the same resources (used for accomplishing complex routines), the contribution to quality improvement of RFID use is mainly linked to human error prevention and reduction of subjectivity impact. Operationally when a component (or a batch of components: case tagging) arrives to a specific workstation, the reader checks if it is the right location and identifies the operations to be carried out. This is particularly important in an MTO environment where the customisation level is quite high; thus, the existence of a high variety of production routings increases the probability of human mistakes. These applications are of particular interest for companies belonging to sectors, such as aerospace (Airbus and Boeing) and defence, where the manufactures must meet customer as well as public bodies regulations (FAA/DoD/NASA).

RFID can also indirectly, through the detection of unusual production times and/or RFID reader inactivity, provide information about a specific workstation breakdown and improve the reaction time to this kind of failures. Furthermore, if RFID tags are also associated to workstations, it is easy to access in real time all the required information, in terms of history of operation and maintenance, thus reducing downtime.

5.7.2.4 Life Cycle Management

The use of RFID contributes to various improvements concerning product life cycle management, to note is its application to better target product recall actions. This is possible because with RFID as it is easier to identify the finished products for which components belonging to defective batches have been used. In fact, track and trace is fairly easy with RFID because the history of product or material can be tracked at a very detailed level in the following areas: Where the product or material came from? Who did what to it? Where it is? and Where it has been? (date of manufacture, customer order number, loading bay, and shipping data).

The improvement of the efficiency of reverse logistics activities is particularly interesting when, such as the case for MTO and ATO, the same components are used for a wide range of subassemblies and finished products and thus not being able to identify the single product can lead to huge and extremely expensive product recall campaign involving several hundred thousands of items (automotive companies, Nokia, Dell, etc.).

5.7.3 RFID Application in ATO Manufacturing

The ATO is a hybrid model, where one part of the production process is "push" managed on the basis of demand forecasting, whereas the final assembly is "pull" managed in function of the customer demand. The ATO basically shares all the aspects of the MTO, considering that the final production stages are managed exactly in the same way and that the number of finished product configurations that can be obtained assembling the "standard" subassemblies is usually high. For instance, QSC (Audio Products of Limited Liability Company) an audio products manufacturer was able to move from MTS to ATO and successfully introduce a line of customised products thanks to the introduction of a smart convoyerised assembly system using RFID technology (Feare 2000). Product complexity is also fairly important for ATO. Two main trends related to RFID use are simultaneously present:

- Reduction of WIP and inventory level thanks to better forecasting and better control of the internal and supply chain processes
- Modification of the manufacturing typology towards MTO (shift upstream of the OPP)

Typical representative of this manufacturing typology is the automotive sector that is particularly involved in RFID use (46% of all use). For this reason, many of the examples cited in this section belong to this sector.

The applications already outlined for ETO and MTO manufacturing also apply to ATO, thus RFID can be used for the following activities:

- Movable asset management (Volkswagen: special racks for car body parts transportation)
- Production mistakes prevention (Vauxhall Motors: assembly of customised Astra; Ford: production process automation and product efficient routing; Harley–Davidson: easier product customisation by linking a motorcycle's serial number to individualised assembly instruction)
- Finished product tracking (BMW: real-time finished products location system at its production plants in England and South Africa, based on active RFID tags)
- Components, subassemblies, and finished product traceability (In 2000, the famous recall of 14.4 million Firestone tires caused Ford a loss of approximately $ 2.6 billion; now, with the Transportation Recall Enhancement, Accountability

and Documentation Act, it is illegal to sell new passenger cars lacking RFID in the tires; Grammer, a German manufacturer of seats for cars, trucks, and off-road vehicles, is using RFID to save time and money in locating seats and accessing their production information in the event of a recall)
- Product life cycle management (End-of-life recycling regulations, especially stringent in the automotive sector where furthermore a precise identification of each component and of its materials is required for applying appropriate reuse/recycle processes)

The tags are usually directly attached to the components/finished products or used for the management of movable reusable assets. In the automotive applications, there is a wide use of active tags for ensuring long-range lectures. ATO being a hybrid between MTO and MTS, the introduction of RFID is facilitated in the upstream production phases where a limited number of standard components and subassemblies are produced according to well-specified routings. This can also facilitate the application of JIT techniques to the upstream production processes.

5.7.4 RFID Application in MTS Manufacturing

MTS is characterised by a relative low variety of products having usually relative big sales volumes. Thus, production resources are usually organised in production lines to increase efficiency. The recourse to dedicated production lines partially reduces the needs of movable assets, thus also decreasing the importance of using RFID for tracking them. The establishment of RFID infrastructure in MTS context is facilitated by the dominant product-oriented manufacturing system; in fact, the degree of freedom of the material flows is constrained by the use of production line thus reducing the number of readers required for achieving satisfying read rate accuracy and velocity.

For MTS, the primary objective of RFID introduction is not ensuring the right material flow (because of the complexity and variety reduction) but improving efficiency and production resource use. Labour and manufacturing resources productivity are crucial in production lines where the production phases must be balanced and synchronised and various equipments are more or less rigidly interconnected. RFID applications can support productivity improvement (Qiu 2007) through:

- Preventing production mistakes while avoiding manual non-added-value inspection activities
- Providing all the production information and parameters at the right time and at the right place
- Providing timely information about resource use and queues length, allowing a "real-time" dynamic management of bottlenecks, and offering opportunities for process redesign

In MTS, all production phases are managed on the basis of forecast and this requires the establishment of inventory to deal with uncertainty and variability. The use of RFID can improve the visibility about finished products/subassemblies/components/materials stocks as well as about WIP and thus allowing reduction in inventory management costs while further improving efficiency. The extension of RFID use to the down-stream phases of the entire supply and distribution chain also allows to timely improve forecasting quality based in reliable point of sales information and the application of more sophisticated production-planning and control policies.

Many RFID applications in the MTS context belong to the semiconductor and computer manufacturing industry (Hewlettt-Packard, Intel, Motorola, SGS Thomson, Wacker, etc.). The complexity of back-end semiconductor manufacturing processes (30 processes that can be regrouped in this macro phases wafer mount, saw, die attach, cure, wire bonding, plasma cleaning, mark, singulation, and inspection) justifies the massive application of RFID for enhancing the performances of process automation (Qiu 2007). RFID coupled with a shop floor information system, being an interface between enterprise planning and shop floor execution, allows to improve productivity (better yield, labour reduction, floor space optimisation, production cycle reduction, visibility increase). Case-level RFID has been applied by Hewlett-Packard for gathering timely and accurate inventory-level information to avoid stock checks and reduce control costs of 20% (Chopra and Sodhi 2006). In an RFID pilot application at case level, Intel tracks the microprocessors movement from the end of the manufacturing line through Intel's warehouse to the point of use in the customer's manufacturing line. Additionally, to the higher inventory visibility and the improved efficiency, the data availability provided by RFID allows to uncover and solve completely unexpected issues. The potential benefits of extending RFID use beyond the company boundaries have been shown in the pilot study. It is also recognised that to fully exploit the improved data yielded by RFID, significant changes to information systems and management practices have to be introduced.

5.7.5 RFID Applications in Retailing and Distribution

Retailing and distribution do not imply production processes; however, according to the manufacturing typology, they can have a significant impact on the overall supply chain activities of manufacturers. For this reason, a brief description of RFID applications in retailing and distribution is also provided here. Moreover, big retailers, such as Walmart and Tesco, promote RFID adoption, "forcing" many MTS manufacturers belonging to the consumer-packaged goods sector to join their projects.

The largest area of RFID adoption has been supply chain management issues in the retail industry. Based on empirical and analytical studies, retailer benefits include (but are not limited to): labour cost savings; operation time savings;

increased order fulfillment rate; higher inventory turnover rate; greater quality assurance of products; shorter order lead times; and reduction of average inventory, shrinkage, lost sales, safety stock, human errors, forecast errors, and paper work.

Thanks to RFID retailers' increased receiving efficiencies, this can have significant benefits considering that they typically source a large variety of products from many suppliers in case quantities. Moreover, shipments from a single supplier to a retailer often contain multiple products. Most large retailers source in case quantities or more. Thus, case-level RFID significantly improves efficiencies relative to the use of bar codes by automating the receiving process. Case- and pallet-level applications are predominant also because at the current prices, item-level tracking by RFID is cost effective only for high-priced items (computer games, DVDs, prescription drugs, jewellery, etc.).

Generally speaking, retailers that have high-inventory turnovers and more contact with customers have a higher risk of accumulating inventory discrepancy compared with distribution centres, which have lower-inventory turnovers and less contact with customers, and thus can expect greater benefits from RFID adoption. However, empirical proofs exist for RFID usefulness in distribution and logistics players. For instance, GENCO, a large international distribution and logistics company, greatly improves the performances (improved efficiency, reduced operational costs, improved customer satisfaction, and shortened order cycle time) of its warehouse management system thanks to RFID introduction. GENCO adopted an integrated solution that combines the use of active and passive tags as well as tracing and tracking of movable assets and of finished products (cases or pallets). This example also shows how different types of benefits can be simultaneously reached according to the fixed objectives. The simple replacement of manual tasks, achieved with automatic warehouse management, is coupled with the optimisation of various processes and of resource use, thanks to a complete dynamic management of the entire material-handling solution (choice transportation resource, calculation of optimal (Stock keeping unit (SKU)-picking sequence and resource path). GENCO pilot also underlines how technological barriers can limit the scope of RFID application; in fact, a 60% of case-level reading reliability suggest to apply the RFID infrastructure mainly at the pallet level where the reading reliability even for the pilot is far greater (96%).

5.8 Conclusions

This chapter presents an overview of RFID applications mainly focusing on management aspects and underlines the relationships among manufacturing typologies and the various aspects of a suitable RFID strategy. A broad range of RFID applications is presented avoiding the hype linked to well-known successful (retail) cases but focusing on manufacturing applications and exploring the impact and the justifications of the selected strategies. The best practices presented here can inspire companies thinking about implementing an RFID infrastructure. Furthermore, the identification of the influencing factors and the description of their influence allow a manufacturing company to easily select potentially beneficial RFID applications and provide the checklist to be followed while developing their implementation and deployment.

The theoretical framework of analysis introduced in this chapter allows better understanding of the contents of the following two chapters, where specific issues are recognised and analysed according to the objectives and the constraints characterising their implementation context.

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Chapter 6
A Versatile ERP–RFID Interfacing Scheme

Luca Gamma, Andrea Massimini and Eric Muller

Abstract Enterprise resource planning (ERP) software usually implements interfaces to identify and keep track of objects when moving from stock to the delivery pallet. In most cases, such kind of pseudo-automation is accomplished using printed barcodes. The overcome of radio frequency identification (RFID) requires ERP developers to offer a new kind of interface to deal with this technology. An RFID infrastructure is a set of hardware and software components required to manage and interact with end devices (i.e., the RFID tags) from human interfaces, such as computer programs or handheld readers. In this chapter, we focus on the design and the implementation of an RFID–ERP integration stack starting from the hardware layer to the application layer. The testing scenario (demonstration environment) will be an RFID infrastructure able to ease inventories and track luxury items in jewelers.

6.1 RFID–ERP Integration Model

The common way to interface legacy ERP solutions with RFID infrastructure requires the design of an integration model separated in layers connected one to each other. Figure 6.1 depicts the envisaged model stack, whereas in the subsequent sections, we describe the functionality of each layer.

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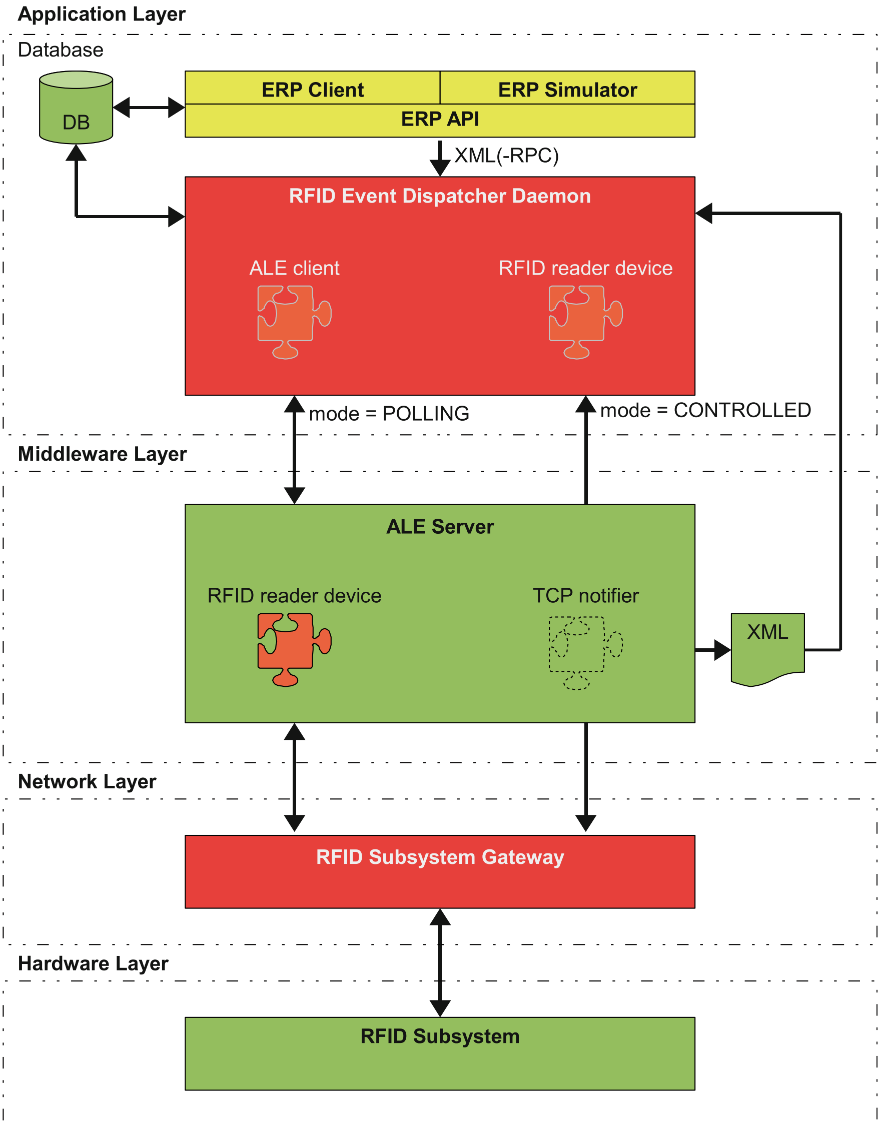

Fig. 6.1 Integration model stack

6.2 Hardware Layer

The RFID subsystem represents the hardware layer of the RFID infrastructure and consists of RFID readers, RFID antennas, and, of course, RFID tags.

The readers are able to communicate with tags in both ways, read, and write depending on the tag capabilities, whereas the operating frequency bands depend on the target application. The main frequencies in use nowadays are:

- Low-frequency (LF): 125–143 kHz
- High-frequency (HF): 13.56 MHz
- Ultra high-frequency (UHF): 400 and 860–960 MHz
- Microwaves: 2.45 and 5.8 GHz

LF and HF are most used in implantable devices (human or animals) where the data transfer rate is not mission critical, the reading distance ranges from few centimeters (LF) to about 1 m (HF) and/or the device has to be responsive inside or around liquids (e.g., water or bodies). UHF and microwaves are most used where a fast data rate is required and the minimum reading distance starts from 1 m on.

Here follows an example of RFID subsystem running at the Telecom, Telematics and High-Frequency laboratory of University of Applied Sciences of Southern Switzerland consisting in two HF RFID readers, two HF RFID antennas (only one shown in the picture), and HF RFID tags. These components will also be used in our prototype to add RFID capabilities to the existing ERP solutions.

6.2.1 HF RFID Reader

The long-range HF RFID (Fig. 6.2) reader is capable of driving two antennas with a maximum output power of 4 W. Configuration and control of the reader is done via industry standard RS-232 serial interface and communication protocol is well documented and can be ported to any operating system running on PCs or other control devices.

Fig. 6.2 HF RFID reader

Fig. 6.3 HF RFID stack antenna

6.2.2 HF RFID Antenna

This is an HF RFID stack antenna (Fig. 6.3) meaning that objects can be read even if stacked over each other's and supports a maximum input power of 1 W. Stack antennas are the ideal choice for the final application envisaged to test and verify our implementation while they can be easily mounted under counters or work tables.

6.2.3 HF RFID Tag

The rugged HF RFID tags (Fig. 6.4) use a passive transponder and dispose of a read-only 64-bits unique identifier and 1,024-bit of lockable read/write memory

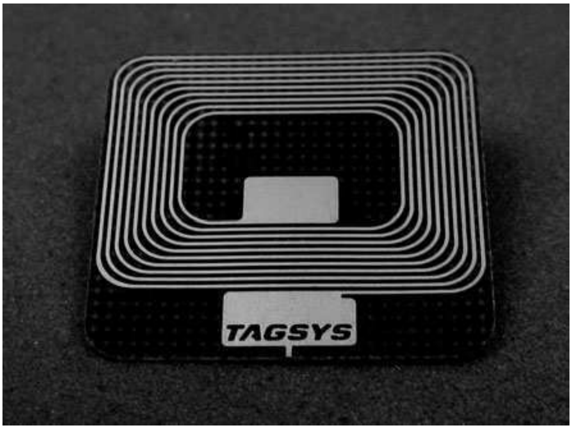

Fig. 6.4 HF RFID tag

available for the application. Form factor of this tag makes it suitable for plastic injection molding and then integrated into jewel's label enclosure.

6.3 Network Layer

RFID readers are generally driven by dedicated computer system and the number and different models/makers of such readers may become very large in production or stock plants. Using RS-232 interfaces can dramatically limit the connectivity in terms of number of readers controlled by a single PC and in terms of distance between them. Offering an ethernet connection makes the reader more versatile and embeddable into a heterogeneous network. RFID reader software should be able to offer options to connect the reader via an ethernet interface and for such reason, we added a network layer to ensure ethernet connectivity to all the readers in the RFID subsystem.

Our reader has only RS-232 interface and hence we need to implement a serial to ethernet device able to add networking capabilities to the reader himself. Various black boxes do this work but for easy startup, costs, and simplicity, we use spare PC (namely, the RFID Subsystem Gateway) running open-source software (Linux) and a daemon (ser2net) that redirects all the traffic on a given serial port to a given IP port number of the local ethernet interface. In this way, two RFID readers can be accessed using a single ethernet interface from any network-enabled device.

6.4 Middleware Layer

The RFID middleware is a software layer that sits between the hardware interface (RFID readers) and the application software interface (ERP). In RFID infrastructures, it is important to collect and precisely identify RFID tags by applying filters to avoid redundancies (i.e., multiple readings of the same tag); this is the main feature of the middleware layer. Other features include: data exchange with the software application via so-called event notifiers (upstream) and bidirectional communication with RFID tags via so-called devices (downstream).

Different middleware packages are available around the internet, some having commercial license while others having free license for non-commercial use. The goal of our infrastructure is to build a demonstration environment and hence an open-source solution (e.g., LogicAlloy ALE Server) will be a good choice. The middleware we used is entirely written in Java making this software portable over different operating systems (Linux-based, Microsoft Windows, and Mac OSX) and extensible by adding or modifying middleware plug-in classes (notifier and device). Notifier plug-ins are used to notify RFID events (i.e., the reading of a tag) to external applications (upstream), whereas device plug-ins are used to manage the RFID reader (downstream). Out of the box, our middleware supports a large number of notifiers; on the contrary, we need to implement a customized device plug-in to drive the RFID reader.

6.5 Application Layer

On top of our RFID infrastructure, there is the application layer consisting of a custom module (i.e., the RFID Event Dispatcher Daemon) and the ERP application-programming interface (API). The custom module captures RFID events generated by the middleware and translates this information in SQL queries to save data persistency in database tables. This database is then used by the ERP to manage and locate the tagged items. The API is designed by the ERP developer and should offer a high level of control over the RFID middleware and RFID subsystem. This interface can then be shared between the ERP clients (dedicated modules plugged into the ERP software suite) and the ERP simulator (a stand-alone application used to verify the functionalities exposed by the ERP API).

6.6 Conclusions

Commercial ERP providers usually use barcodes to track products or items along the supply chain. Barcodes are cheap and easy to apply on items; they can be directly printed on packages but is difficult to automate code capture operation. Even the reading requires particular attention while the barcode should be always in a line-of-sight with the reader.

RFID technology comes in aid to the barcode limitations offering a number of advantages. Introducing RFID in supply chains also means changing (part of) the enterprise software which has to interact with a new kind of infrastructure. For this reason, software providers have to be ready to integrate and then offer RFID support in their products.

The resulting prototype following the above integration model demonstrates how to add RFID support to existing enterprise software, such as ERPs using third-parties' middleware and adding a small piece of custom software and plug-in modules.

Chapter 7
Business Process Management (BPM) and Web 2.0 as Key Enablers for the Future Knowledge-Based Digital Factory

Myrna Flores

Abstract Business Process Management can be considered a powerful catalyst to increase companies' innovation capabilities by exploiting and coordinating firms' processes and resources in an optimal way. In a digital factory, processes do not only require useful information as input but also the possibility to capture, share, and reuse knowledge to increase workers productivity. As a consequence, there is a current need to evolve from old generation factories that exchange information among specific or closed working groups and/or individuals in silos to the next generation of digital- and knowledge-based factories where relevant business processes content is coauthored and shared among all workers. Additionally, companies need to collaborate with distributed internal and external networks to carry out different processes in a collaborative and concurrent way, in particular with customers and suppliers. On the other hand, Web 2.0 functionalities, such as wikis, blogs, tags, among many others, promise a new digital business ecosystem enabling formal/informal and internal/external relationships and interactions. Thus, this chapter briefly presents the applied research carried out in the Swiss DiFac project by SUPSI and CEMEX Research Group to cocreate the SMARTBRICKS Web 2.0 prototype to foster an open-collaborative space for business processes knowledge sharing and contents cocreation.

7.1 Introduction

The Intelligent Manufacturing System (IMS) Digital Factory (DiFac) collaborative research project aims to develop a strategic-planning design tool that is capable of

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supporting the construction of a digital factory. The Swiss IMS DiFac project covers the work package dealing with the Enterprise Resource Planning (ERP), proposing a new industrial engineering system that should not only integrate information and knowledge from the production process but also the complete product life cycle as shown in Fig. 7.1 (Flores et al. 2007).

To accomplish this objective, research targets the testing, implementation, and diffusion of novel information and communications technology technologies, such as Semantic Web, RFID, and discrete event simulation. CEMEX Research Group is partner of the Swiss DiFac project, and its main interest is the development and testing of a Web 2.0 prototype called SMARTBRICKS. This need was identified because ERPs do not provide the required open-collaborative space to allow different users that operate in the different business processes providing contents in a flexible way; thus, the proposed new tool enables CEMEX employees to share

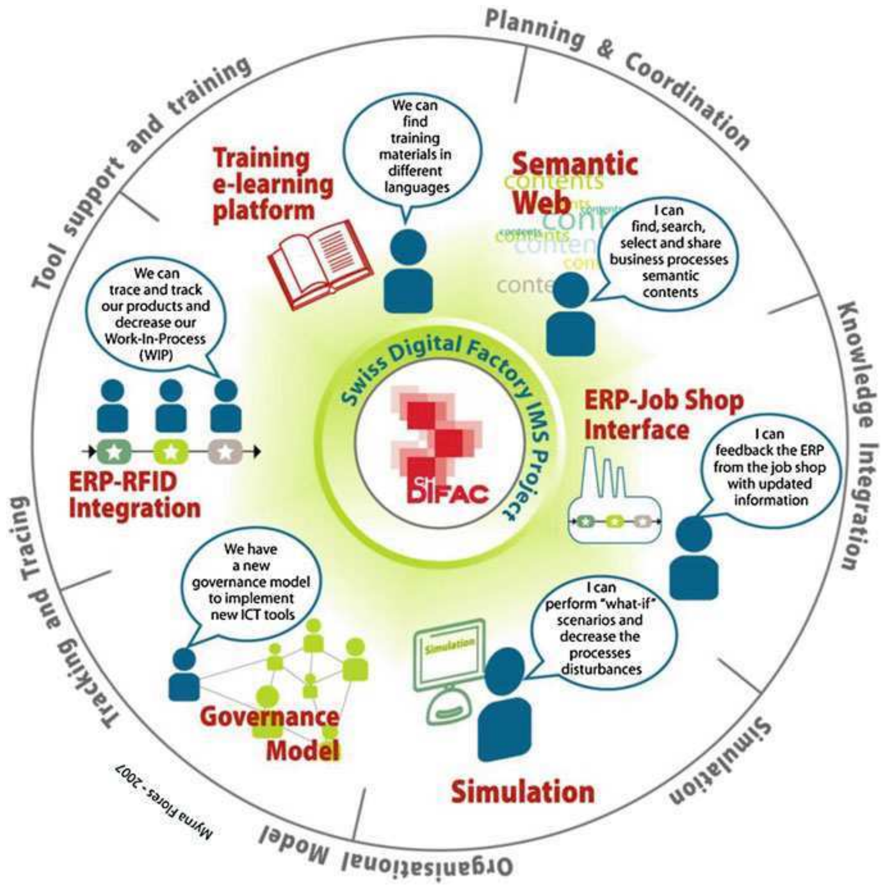


Fig. 7.1 The Swiss DIFAC project overall view (Source: Flores 2007)

information and knowledge by exploiting Web 2.0 functionalities for Business Process Management (BPM). In other words, BPM specialists evolve from "passive consumers" of business processes contents to "active contents developers" and accelerate BPM best practices global diffusion and sharing (Flores et al. 2009a).

7.2 Integrating Business Process Management and Web 2.0

CEMEX is a global building materials company, the world's largest building materials supplier and third largest cement producer, providing both products and services to customers and communities in more than 50 countries throughout the world. Initially when CEMEX began acquiring organizations around the world during the 90s, business leaders realized that best practices were not frequently shared. Best practices usually refer to proven techniques or methods that have provided efficient and measurable economic returns. Some identified reasons against implementing best practices from one CEMEX location to another were the differences in cultures, languages, processes, and local laws (APQC 2004).

As a result, CEMEX launched an internal project to determine how information tools could add value to the operations within organization and facilitate the exchange and sharing of such best practices to increase its global operational efficiency. In fact, CEMEX is recognized for its capability of renewing and replicating itself because of the high level of intelligence based on digital productivity, developing better and more sophisticated information technologies (IT) and training systems for generating knowledge than many services firms (Slywotzky and Morrison 2000).

The organization realized that to deploy the same IT platforms and systems at a global level, a standard business process architecture based on a set of common business processes was required. Therefore, the outcome of the project was the birth of the CEMEX Way (Fig. 7.2), which targets:

(a) A standard blueprint for managing processes across the world in all operations.
(b) A process for use in all post merger and acquisition integrations.
(c) A methodology that allows the organization to continually evolve, identify and adopt best practices, and promote innovation.

7.2.1 Business Process Management and Its Relevance to Gain Competitive Advantage

During the CEMEX Way implementation, the company realized the importance of implementing a BPM approach. One key objective of BPM is a clear and formal description of an "end result" that a firm intends to achieve through well-defined intermediate goals, where particular care must be given to indicate "what" must be achieved, "why" for "whom" and "within what time limit".

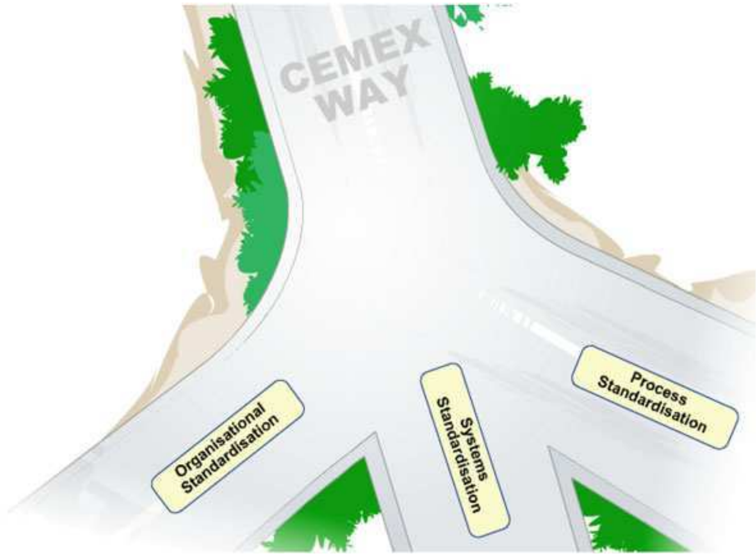


Fig. 7.2 The three main components of the CEMEX Way (Source: CEMEX 2000)

According to the International Organization for Standardization (www.iso.org), every organization exists to accomplish value-adding work. Such work is accomplished through a network of processes. Every process has inputs, such as information and materials, and outputs that are the results of the process. The *Oxford Dictionary* describes a process as a course of action, a series of operations, or a series of changes.

Business processes have to be classified in a manner that can be searched to perform specific actions on products. A process can be described in terms of what it can deliver as an output, for example, development and design, manufacturing, production, packing, service, distribution, etc. APQC (2005) defines a process as a series of interrelated activities that convert inputs into results (outputs), processes consume resources and require standards for repeatable performance, and processes respond to control systems that direct the quality rate and cost performance. As a result, a process-centric organization is a company that is organized, structured, measured, and managed in terms of business processes (Wolf 2004). Figure 7.3 shows the integration of strategic business processes and implementation levels when targeting an end-to-end process organization. Table 7.1 compares a process-centric organization with a nonprocess-centric.

Executives in process-centric organizations do not see their organizations as sets of discrete units with well-defined boundaries. Instead, they see them as flexible groups of intertwined work and information flows that cut horizontally across business, ending at points of contact with customers (Hammer and Stanton 1999).

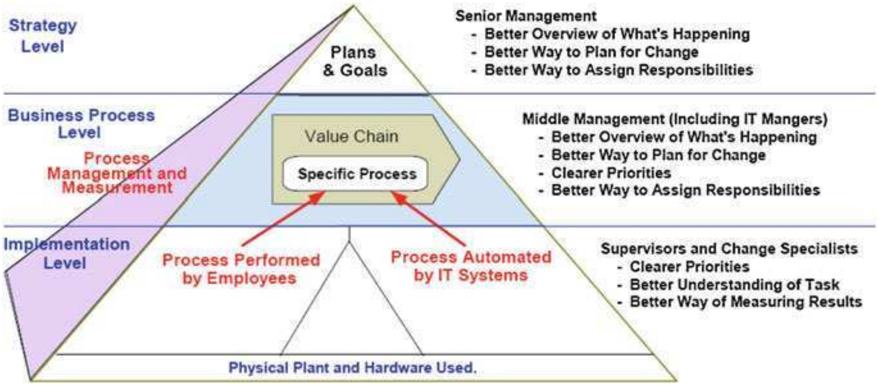


Fig. 7.3 End-to-end process centric organization management concerns (Source: Harmon 2005)

Table 7.1 BPM fundamental domains (Source: Melenovsky et al. 2005)

Process-centric company	Nonprocess-centric company
Understands that processes add significant value to the organization; understands that processes are a significant contribution to the fulfilment of an organization strategy.	Does not fully appreciate the contribution that processes make to the organization and the realization of the organizational strategy.
Incorporates Business Process Management (BPM) into the management practices of the organization.	Management of processes is not a primary focus.
Embraces a BPM strategy.	Supports various BPM initiatives.
Senior leadership focuses on processes (specially the CEO, because others follow the leader).	Understands that processes must be important because of the problems they may cause (quality, backlogs, etc.).
The organization's structure reflects this process understanding, with either a structured designed around processes or a matrix reporting or processes and functional responsibilities.	Organizational structure is based on functional departments.
Understands that tension can arise between process and functional lines of responsibility and has mechanisms in place to deal and resolve these tensions, a team understanding and approach.	Becomes frustrated with interdepartmental process issues, and could have a blame mentality; perhaps wishes to (or already has) interdepartmental service–level agreements.
Has appointed senior executives as responsible for the BPM implementation.	Functionally based with no cross-departmental responsibilities.
Rewards and measures are linked to processes outcomes.	Rewards and measures linked to functional department outcomes (silo effects).

In a nutshell, BPM is a management practice that provides for governance of a business process environment toward the goal of improving agility and operational performance (McCoy et al. 2008). BPM is a structured approach that employs

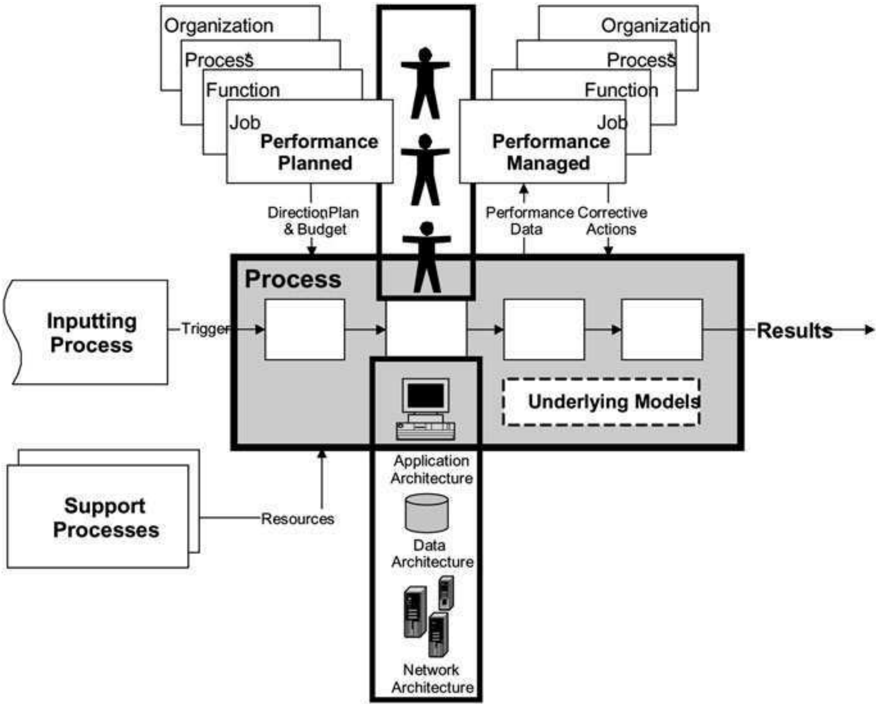


Fig. 7.4 Business Process framework applied in CEMEX (Source: Rummler and Brache 1995)

methods, policies, metrics, management practices, and software tools to manage and continuously optimize activities and processes in any type of organization. This definition has two parts:

1. Describes the scope and intent of BPM—governance of the business process environment and improvement in performance and agility.
2. Focuses on a preferred BPM approach that should include the deployment of a variety of practices in an ongoing manner to continuously optimize process-based performance. These practices should integrate people and technologies aligning them to each of the processes needs. Figure 7.4 presents the business process framework applied in CEMEX.

7.2.2 Knowledge Management and Web 2.0

But what is knowledge and knowledge management (KM) and how are they connected to BPM? There is not one unique definition for either of them. Following Kogut and Zander (1996), knowledge could be understood as recipe that specifies how to carry out activities. Devenport and Prusak (1998) define knowledge "as a fluid mix of framed experiences, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories, but also in organizational routines, processes, practices and norms".

In regard to the knowledge-based theory of the firm, it was developed by Winter (1987), Kogut and Zander (1992), Nonaka (1994), Nonaka and Takeuchi (1995), Grant (1996), and many other authors who have contributed for its diffusion and continuous evolution (Flores et al. 2009a). For instance, Wiig (1993) states that KM is the management of corporate knowledge that can improve a range of organizational performance characteristics by enabling an enterprise to be more "intelligent active". Marshall (1997) referred to KM as the harnessing of "intellectual capital" within the organization. According to Seemann et al. (1999), KM can be thought of as the deliberate design of processes, tools, structures, etc., with the intent to increase, renew, share, or improve the use of knowledge represented in any of the three elements (structural, human, and social) of intellectual capital.

Within a factory context, workers are creating more documents and records than ever. This explosion of unstructured information, such as documents, e-mails, and Web content, often results in disorder if the content is not created, tagged, versioned, controlled, and managed in a consistent global manner. As a result, in most of the cases, employees cannot find the information they need to complete a task or business process and cannot share it with others; enterprises are facing greater risks from the loss or misuse of knowledge, sensitive and relevant information required to accomplish tasks within the different business processes. Moreover, most tools currently used in factories are very limited in allowing search and navigation by knowledge workers to find the right information and reuse of available knowledge. As a result, there is a current need to incorporate new Web 2.0 functionalities for BPM.

On the other hand, the term "Web 2.0" describes the changing trends in the use of World Wide Web technology and Web design that aim to enhance creativity, communications, secure information sharing, collaboration, and functionality of the Web. Web 2.0 concepts have led to the development and evolution of Web culture communities and hosted services, such as social-networking sites, video/contents sharing sites, wikis, and blogs (Colomb 2007). Figure 7.5 and Table 7.2 provide some insights of the key characteristics and benefits of Web 2.0 according to Dawson (2007).

According to McAfee (2006), when the Web 2.0 functionalities are applied in an organization, then it is called Enterprise 2.0 (Dawson 2009). This latter refers to the usage of Web 2.0 tools as a strategy within a company to benefit the different business process from Web 2.0 functionalities. This author has also suggested the acronym SLATES (Fig. 7.6) to refer to six components underlying Enterprise 2.0, as employees should be able to search for relevant information, add links to their

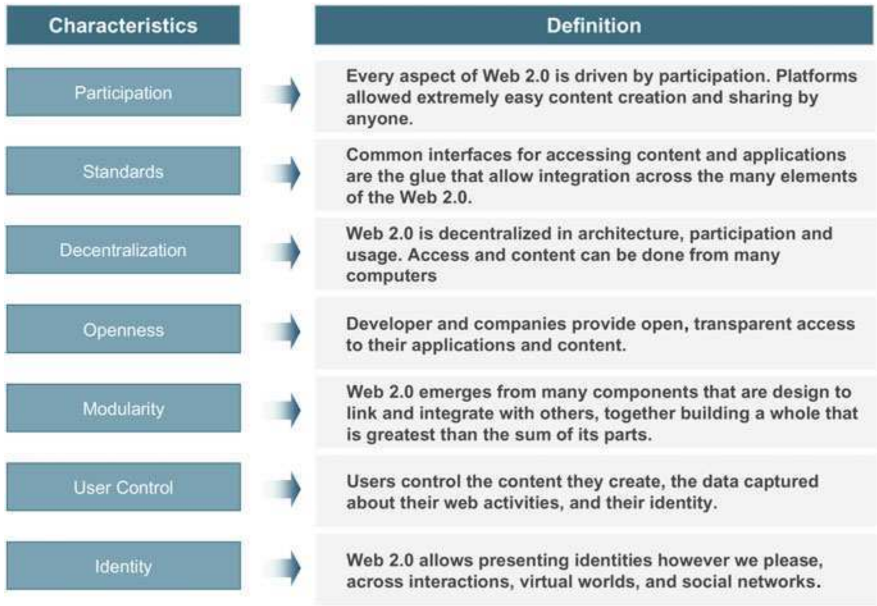


Fig. 7.5 Web 2.0 major characteristics (Source: Dawson 2007)

most used documents, add comments to other available comments by authoring content, tag their most relevant words, etc.

In January 2007, McKinsey carried out an e-survey covering different sectors and different companies around the world to investigate how firms had been using Web 2.0 applications (Table 7.3). As observed from the Fig. 7.7, 75% of the

Table 7.2 Key benefits of implementing Web 2.0 (Source: Dawson 2007)

Key Potential Benefits of Implementing Web 2.0			
Category	**Benefit**	**Overview**	**Relevance**
PRODUCTIVITY AND EFFICIENCY	Increased Productivity	People and teams work more effectively through quicker access to resources and easier collaboration.	Any knowledge- based work especially in teams
	Faster Innovation and product development	Both early stage innovation and taking products through to launch is made more effective by fluid interaction	Organizations driven by innovation or with short product cycles.
	More efficient project management	Enterprise 2.0 tools are extremely relevant to streamlining project management across all domains	Any project teams, particularly those that are multi-location or cross organizations.
	Reduced email overload	Migrating some kinds of organizational communication outside email to create greatest personal efficiency	Where excessive email is impacting productivity.
	Improved team performance	Acceleration of tem interaction and more rapid trust building	Any environment where teamwork is important.

Fig. 7.6 SLATES Enterprise 2.0 six components

Table 7.3 Some functionalities of Web 2.0 (McKinsey 2007)

Blogs (short for Web logs) are online journals or diaries hosted on a Web site and often distributed to other sites or readers using RSS (see below).

Collective intelligence refers to any system that attempts to tap the expertise of a group rather than an individual to make decisions. Technologies that contribute to collective intelligence include collaborative publishing and common databases for sharing knowledge.

Mash-ups are aggregations of content from different online sources to create a new service. An example would be a program that pulls apartment listings from one site and displays them on a Google map to show where the apartments are located.

Peer-to-peer networking (sometimes called P2P) is a technique for efficiently sharing files (music, videos, or text) either over the Internet or within a closed set of users. Unlike the traditional method of storing a file on one machine—which can become a bottleneck if many people try to access it at once—P2P distributes files across many machines, often those of the users themselves. Some systems retrieve files by gathering and assembling pieces of them from many machines.

Podcasts are audio or video recordings—a multimedia form of a blog or other content. They are often distributed through an aggregator, such as iTunes.

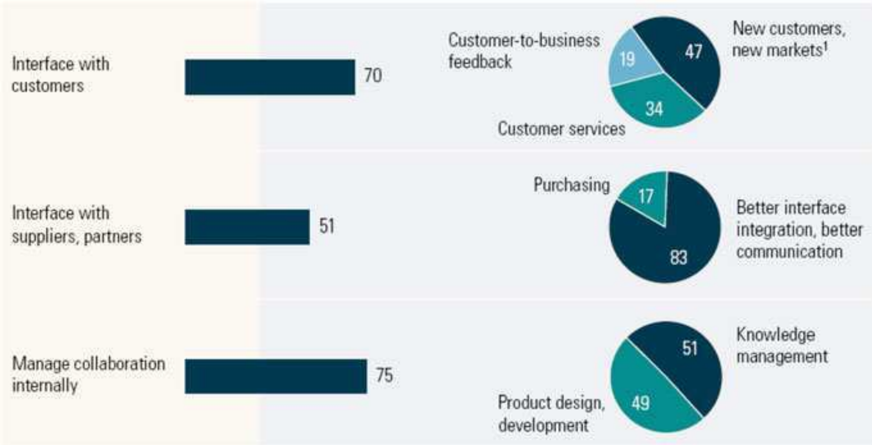


Fig. 7.7 How 2847 executives are using Web 2.0 (McKinsey 2007)

companies in the study use Web 2.0 to manage internal collaboration, focusing on knowledge management and product development. On the other hand, results show that out of the three main purposes, collaborating with suppliers had the least interest, especially when applied in the purchasing business process. The interface with customers is also very relevant when using Web 2.0, especially when accessing or developing new markets.

7.3 AS-IS and TO-BE Scenarios to Implement Web 2.0 Functionalities for BPM

In this section, the AS-IS (Table 7.4) and TO-BE (Table 7.5) scenarios are presented to provide more context of the current and future needs to develop the SMARTBRICKS Web 2.0 prototype for BPM.

7.4 Developing the Web 2.0 SMARTBRICKS Prototype

The SMARTBRICKS prototype aims to enable digital factory workers to share business processes and best practices information and knowledge by exploiting Web 2.0 technologies. The main objective, as shown in Fig. 7.5, is to catalyze the development of BPM skills to be deployed in new processes improvement projects at a global level. Relevant contents are easily found by the use of tags and specialists coauthoring BPM contents. SMARTBRICKS enables Just-in-Time right and pertinent contents to be created and accessed by the single employee (Fig. 7.8). The successful implementation considers the direct interactions among people, processes, and technology.

Table 7.4 AS-IS scenario regarding the old and conservative factories that exchange information among some working groups and/or individuals in a poor way

1.	We are a multinational company that has manufacturing sites, distribution locations, and offices in the five continents.	
2.	Workers in most cases do not codevelop dynamically business processes information and knowledge. There is no tool or guidelines to collaboratively formalize and coauthor business processes contents in a distributed environment using a unique platform.	
3.	The company has not defined a process to enable employees to share semantically their business processes contents. Time is consumed when workers search for useful business process contents. Even if they have been done before, as they do not find them, they have do be redone, therefore is costly for the company.	
4.	Currently, business-related knowledge contents are poorly shared, rarely formalized, coauthored, and reused. Available tools are not sufficient to enable the formation of collaborative environments where for many multicultural stakeholders, it is not easy to use and learn from contents.	

7.4.1 *The SMARTBRICKS Prototype Key Functionalities and Look and Feel*

The main identified elements during the requirements-gathering phase for the BPM SMARTBRICKS prototype are: BPM wiki, training, methodologies, best practices, business process architecture, process change management, and BPM research projects (Flores and Sommaruga (2009)). Each of these elements is considered a "Brick" as shown in Fig. 7.9.

Each BPM knowledge worker who accesses the SMARTBRICKS tool is considered a "Bricker". Each Brick has Web 2.0 functionalities, such as blogging and tagging. Every Bricker will have their own space known as "My Brick", where contents can be uploaded. At the same time, it shows in which community is that Bricker active. Figures 7.9–7.12 provide an insight of the look and feel of some of the Bricks of the prototype.

One important functionality not represented as one Brick in Fig. 7.9 is "My Brick", which shows the profile of the single Bricker. Figure 7.10 shows this space, where each Bricker uploads his/her picture, the location of the Bricker, the communities where she/he is an active member, the files that she/he has uploaded, send messages to other Brickers, and read messages (such as any other chatting system)

Table 7.5 TO-BE scenario toward the next generation of digital- and knowledge-based factories where business processes contents are coauthored and shared among all workers

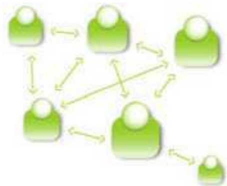
1. Within some months after the DiFac research project started, there is a common understanding of business processes terms in the organization thanks to the BPM Wiki. Business Processes information, methods, and methodologies are now structured, and employees can add their contents uploading documents, adding tags, and writing blogs.

   SMARTBRICKS acts as a networked repository and mediator between the available business processes' contents and the user community (knowledge workers).

2. Training and online videos have been provided to enable workers to search, adapt, coauthor, and share knowledge using the SMARTBRICKS Web 2.0 tool.

   New distributed collaborative networks have emerged developing and self-adapting business processes contents.

   As a result, communities of practice emerge to exchange ideas and learn from each other; stimulating a cross-disciplinary learning on different topics, such as change management, portfolio management, and innovation.



3. A new open-space and proper governance model enable and motivate employees to codevelop, adapt, and reuse business process contents.

   A rewarding system has been designed to assure that employees who share more valuable contents are recognized and awarded by the organization.

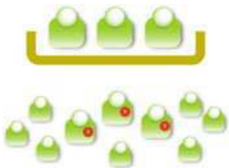


Fig. 7.8 SMARTBRICKS main functionalities

sent by other Bricker. These contents will be published for each Bricker within the section "About us", where all the Bricker profiles can be found.

One main requirement was the collaborative authoring of BPM terms and best practices. As observed in Fig. 7.11, Brickers can add definitions to the BPMwiki, and once each one of them is uploaded, another Bricker can edit the previously provided contents. Last but not least, the Bricker who is reading such definition

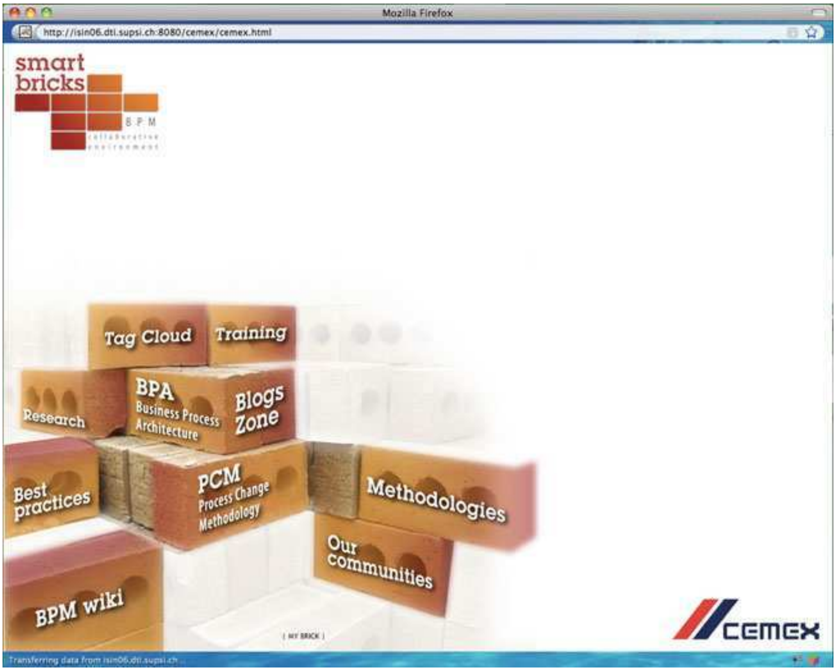


Fig. 7.9 SMARTBRICKS Web 2.0 prototype components or "Bricks"

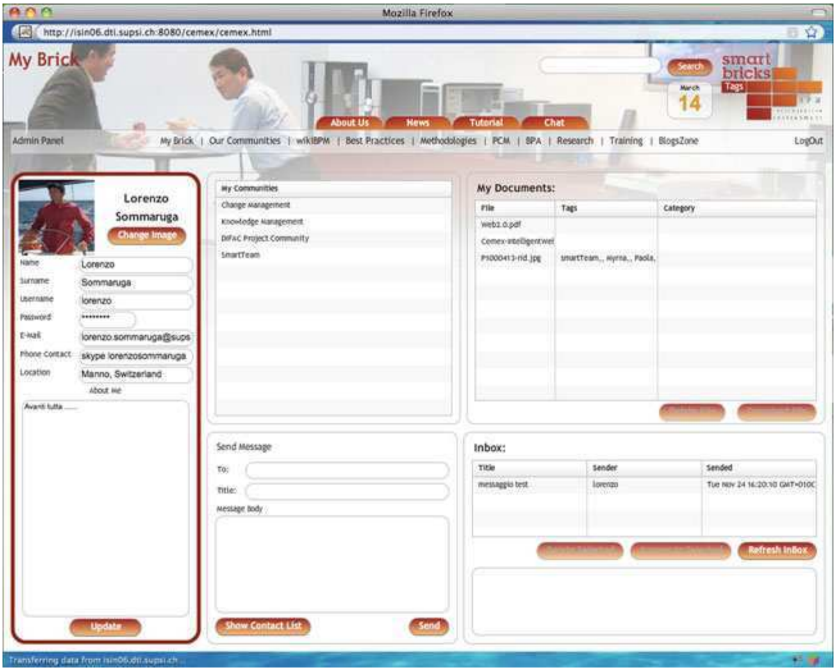


Fig. 7.10 Look and feel of "My Brick"

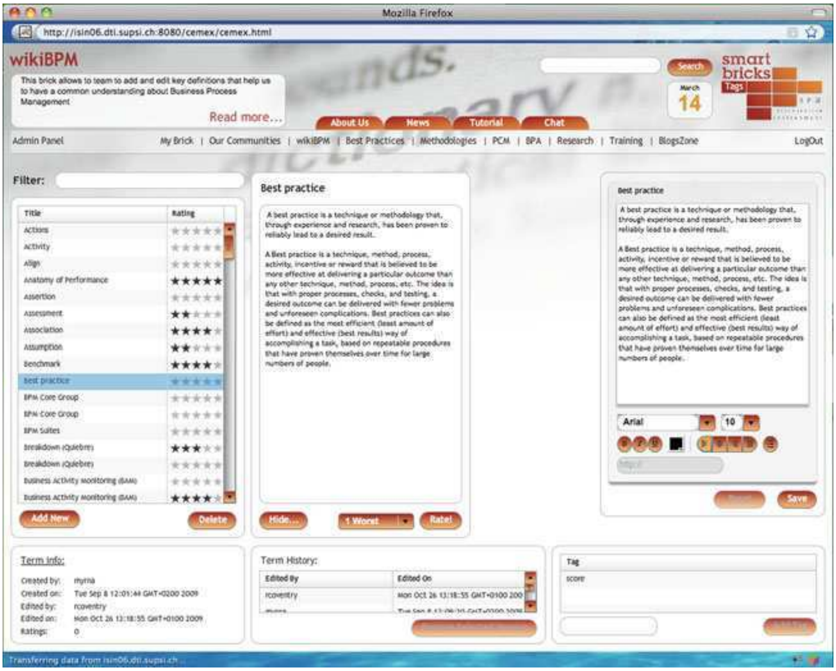


Fig. 7.11 Look and feel of “WikiBPM” Brick

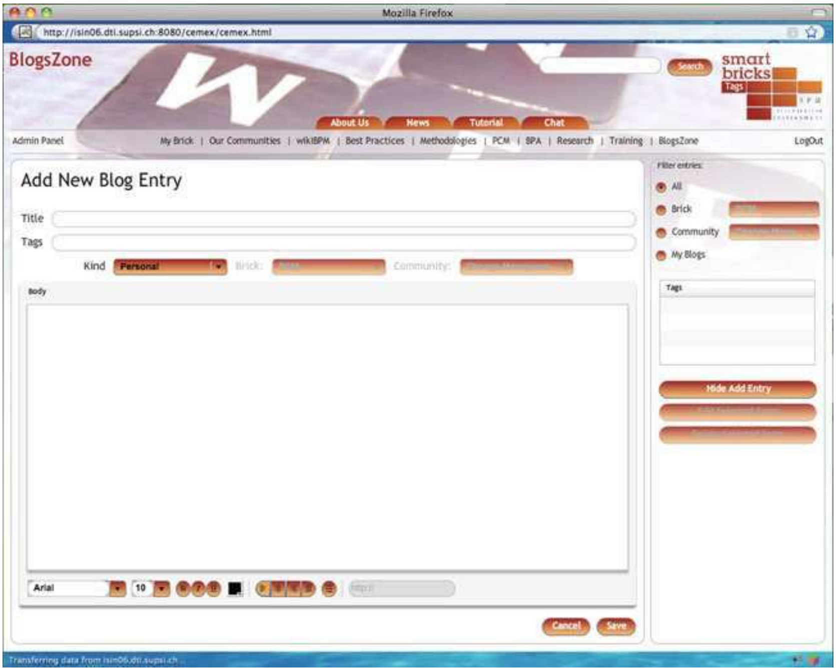


Fig. 7.12 Look and feel of how to add blogs in the blog zone

given to the BPM term can also rank such definition. It is relevant to highlight that SMARTBRICKS also keeps the history (date) of when each of the BPM terms are defined in the BPMwiki. One can thus think that after some period of time, Brickers can review the definitions and update them when needed. By having an updated BPMwiki, the company ensures that all distributed employees can obtain a common definition for each BPM term; these latter are, therefore, continuously being coauthorized.

Another important functionality provided by Web 2.0 are Blogs (Fig. 7.12). As mentioned in Table 7.3, blogs can be considered diaries or open spaces where employees can add their comments as text. Within this Brick, Brickers can add their specific comments and inputs to the SMARTBRICKS. This space represents an open forum for knowledge workers to exchange their ideas and get to know better; specially, when they work in distributed places.

7.4.2 Developing a Standard Taxonomy to Document Best Practices Contents for the SMARTBRICKS BPM Prototype

One critical enabler for the performance improvement of business processes is the continuous learning and implementation of best practices. These latter can be defined as a proved method, procedure, or activity that has provided the best possible outcomes or improvement when being applied to a specific process.

For instance, two successful and very well-known examples of best practices implementation are (a) the Toyota Way, which has been proved to be a best practice for lean production reducing waste, costs, and increasing adding value activities (Liker 2004); and (b) Six Sigma that has proved not only to be a structured statistical methodology to improve and design of processes and products but also a standard way to communicate and manage projects internally, bringing economic returns to companies, such as Motorola and General Electric (Pyzdek 2003).

As a consequence, there is an increasing interest from both large and small organizations to develop, implement, and continuously upgrade industrial best practices (Bogan and English 1994). In fact, Arthur Anderson has created a "Global Best Practices" division, which performs "best practice" audits for companies to identify areas for improvement (Hiebeler et al. 1998).

To develop best practices in the most complete way, a standard taxonomy was developed and applied during the DiFac project in CEMEX (Flores et al. 2009b). The elements of such proposed taxonomy are:

1. *Definition of the best practice*: Description of the meaning of the practice and the reason of the relevance of it within the supply chain.
2. *Background of the best practice*: How and why the best practice emerged, who created it and for what purpose?
3. *Components of best practice and their definitions*: The key factors of best practice, those elements that help the practice to achieve their objectives and have an optimal performance for the supply chain.

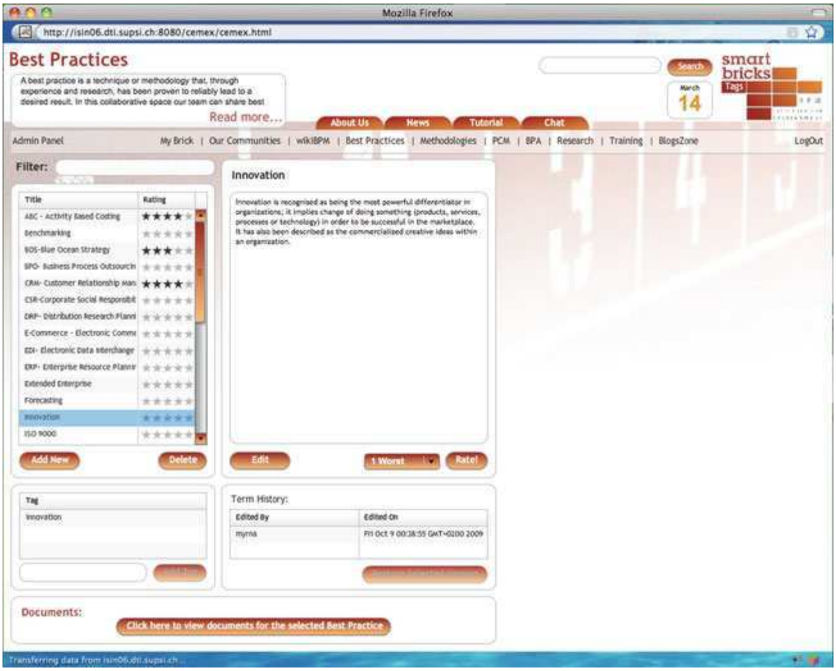


Fig. 7.13 Look and feel of “Best Practices” brick

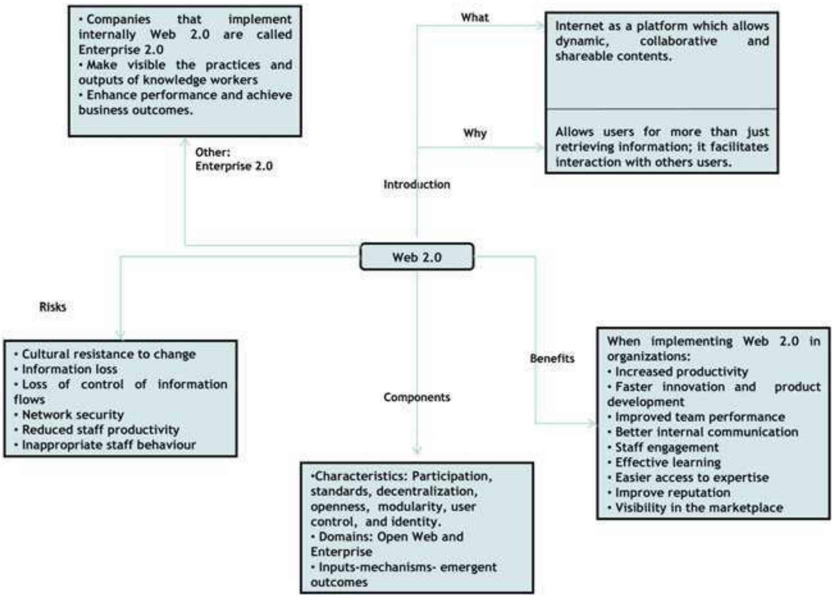


Fig. 7.14 Applying the proposed taxonomy to document Web 2.0 best practices to be uploaded in SMARTBRICKS

4. *Implementation methodology*: It describes the method of implementation of the best practice.
5. *Benefits of implementing the best practice*: Advantages of its deployment, control, and the proper handling of the best practice for the chain.
6. *Limitations*: Restrictions and conditions for the implementation and scope of the practice.

Figure 7.13 presents the screen of how best practices are defined and uploaded in the SMARTBRICKS using the proposed taxonomy as a guideline to standardize their contents. As the BPM terms in the wiki, best practices are also coauthored by different Brickers distributed around the world. Figure 7.14 presents an example of the proposed taxonomy applied to document one of the identified best practices.

7.4.3 Toward a Knowledge Management Maturity Model and Framework as Foundations to Implement the SMARTBRICKS Web 2.0 Prototype

Although the BPM SMARTBRICKS prototype is a very promising tool to enhance collaboration, it is also important to consider the organizational, cultural, and change management elements for its successful implementation. Therefore, a generic KM Maturity Model and Framework are required to assess current collaboration strengths and opportunities before testing, diffusing, and implementing SMARTBRICKS within CEMEX or any other organization. Therefore, this section briefly describes the five levels of the proposed knowledge management self-assessment tool and the knowledge management framework as a result of an extensive literature review and frameworks benchmarking analysis (Flores et al. 2009a) carried out in parallel to the development of the SMARTBRICKS tool:

7.4.3.1 Level 1: Initial

The organization does not have a strategy for KM. Each department, or even each individual, works in its own fashion, there are no common tools or platforms, and sharing is very limited, if existent at all. There are no established goals, and there is no acknowledgment of the KM Process. Even if some tools might be present, such as basic tools or infrastructure (phone and e-mail system), they are not companywide and follow no clear strategy. Also, there is no expressed vision or clear objectives.

7.4.3.2 Level 2: Basic

The company considers collaboration simply as communication; thus, providing basic communication support. At this point, the company lacks clear goals concerning KM, though it might already have a vision of where it would like to be in the future. Tools and infrastructure are the items where the most emphasis has been made, at this maturity level. The knowledge process exists intrinsically, but it is not communicated to all employees, particularly the storage and sharing ones. Concerning support structures, there is no organizational design to improve knowledge transfer; rewarding systems are not in place and there is no time provided to allow employees to share documents, experiences, etc. However, at this stage, the basic infrastructure and tools are in place. Supervisors and employees are aware of the need of sharing information, but knowledge content is created individually, and there is no strong culture of collaboration, beyond superficial meetings.

7.4.3.3 Level 3: Emerging

The company has started to realize how important KM is to remain competitive and increase its productivity and innovation outputs. It has already developed some companywide initiatives, especially in the Knowledge Enablers layer. The company realizes the necessity of properly storing the information. Even though the knowledge process is carried out, it is basically for explicit knowledge; little effort is being done to store and share the implicit knowledge of the individuals, beyond meetings with partial and incomplete minutes. There is some basic organizational design toward a more collaborative environment, but more effort has to be put into developing cross-functional work groups. Companywide information is available in central repositories but of a basic nature, such as file servers. The company is already providing some integrated access to the knowledge repositories and is also starting to experiment with Web 2.0 tools, and some might be available for users. The collaboration culture is emerging and there are more standardized protocols, especially for explicit knowledge. The company has already a clearer vision of where it wants to be concerning KM, there might also be some objectives. But neither expected Business Impact has been analyzed nor Key Indicators been defined. There is no proper alignment of the various enablers toward the global KM Vision, because most of these processes are still being experimented with.

7.4.3.4 Level 4: Expanding

The KM governance is formalized and understood by all employees in the company; a department is dedicated to the successful development of the KM initiative. Infrastructure and tools are carefully designed with collaboration as a goal, rather than as an experiment. Enablers have been optimized, and they are starting to be aligned with the overall KM strategy. Cross-functional tasks and teams are already being implemented. The company has significantly decreased its hierarchical nature. The KM process has now been fully integrated companywide, at least for the explicit knowledge. Also, it has begun to be used to properly capture the more volatile implicit and tacit knowledge. Content is no longer created individually, but in a collective manner by communities. A wide range of tools is available to search and explore the wide knowledge databases of the company. Information is properly organized, and therefore easy to access. Also, thanks to the implementation of Web 2.0 tools, such as tagging, finding the relevant information has become easier than ever. Infrastructure is mature. A collaboration-based rewarding system is in place, although it is in an early stage. Employees, thanks to proper training, are developing the necessary skills and competencies to properly share and transfer knowledge. The collaboration culture is acknowledged as an influencing factor, and therefore as an enabler. The KM strategy has been now properly laid out. The desired business impact of the KM strategy has been established as well as the key indicators to measure the business impact. The company is beginning to align the various elements to its KM strategic views.

7.4.3.5 Level 5: Pervasive

The Knowledge Process is not only integrated inside the company but also with external partners, such as suppliers, clients, consulting firms, and universities. The company has realized that knowledge is a strategic asset. Implicit as well as explicit knowledge is successfully acquired, extracted, stored, shared, and updated by everyone. Knowledge Enablers are not only optimized but are also now fully aligned with the overall KM strategy. Processes are built around collaboration; a rewarding system is now fine-tuned and steadily encouraging collaboration. Every tool available to employees has been optimized and even social-networking applications are being fully used, information is shared freely between colleagues, and employees have completely integrated collaboration to their everyday work. A collaborative culture is fully internalized. The KM Strategy is already in place and is continuously maintained and updated according to changes in the company's internal and external environment. The KM Strategy has had a business impact that can be measured and felt throughout the company. All Knowledge Enablers are aligned properly to the global strategy.

To validate the proposed five steps of Knowledge Management maturity model, an e-survey was designed in Survey Monkey, and 60 employees of the Processes & IT department in CEMEX were invited to fill in the e-survey (Vera 2009). A total of 23 people answered all the questions; the average age of respondents was of 35 years, with the minimum age being 23 and the maximum 46 years. Almost 30% of respondents were female and education was in all cases university-level or higher: 43% at university-level and 57% at post-graduate level. Of all respondents, 76% maintained they worked in a multicultural environment. Figure 7.15 presents the overall results of the e-survey. As observed, in average, this sample is located at the level 3 of the maturity framework; the key opportunity areas identified are:

1. Increase the training of new information and communications technology tools to speed up their implementation (in this case, the Web 2.0 tools).
2. Provide more time to employees to learn and adapt to these KM tools in their daily activities.
3. Develop and diffuse a unique and shared strategy for Knowledge Management.

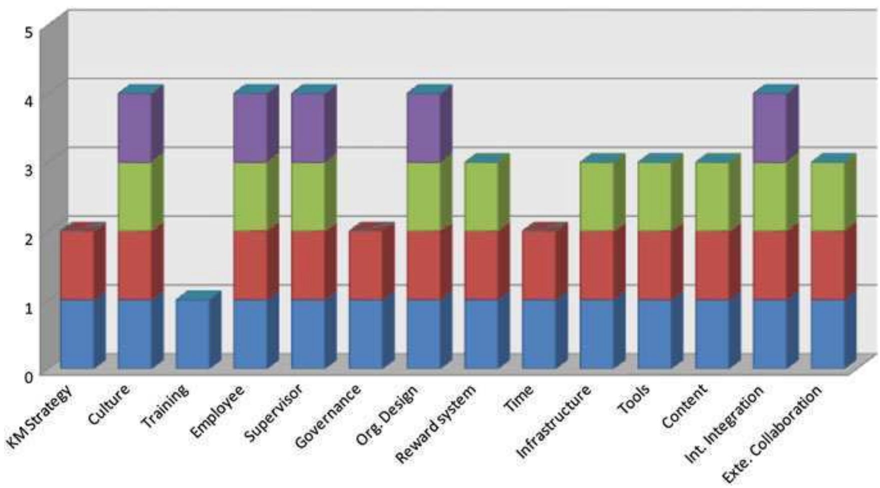


Fig. 7.15 Knowledge management assessment results using the proposed five-levels maturity model in a sample of 23 persons of Processes and IT in CEMEX in December 2008. (source: Flores et al. 2009a)

In fact, one key element for any successful Knowledge Management initiatives within a company is the definition and implementation of a KM strategy. At the same time, its diffusion is a requirement to make it possible to promote best practices, encourage employees share their knowledge and collaborate, instigate managers to value those who do, and thus, finally increase and improve this valuable intangible asset.

The Korean IMS DiFac partners have proposed a schema to model the data required to develop ergonomic analysis considering the process, human, product, and resources required in the manufacturing shop floor to be integrated in the DIFAC Hub (Kim et al. 2008) and more details are also provided on Chap. 4 of this book. On the other hand, the main KM strategy behind the SMARTBRICKS prototype is to provide knowledge and contents in regard to business processes to enable mid-to-top management employees take strategic decisions as shown in Fig. 7.15. In other words, the schema provided by the Korean DiFac project focused mainly on the manufacturing processes of a digital factory, where as the SMARTBRICKS Web 2.0 tool focused on the knowledge contents of the different business process required to manage such manufacturing processes. Such processes relate to sales, purchasing, human resources management, etc., which are needed for the successful operation of the factory as a whole.

7.5 Conclusions and Acknowledgements

This chapter presented the results of the SMARTBRICKS Web 2.0 prototype carried out by SUPSI and CEMEX. Besides the technical challenge to define the requirements to codevelop such prototype to increase the collaboration in the company and facilitate its implementation, it was also identified the need to prepare the organization with tools, such as a Knowledge Management Maturity Framework and a Taxonomy to coauthor the best practices to be shared.

Overall, the SMARTBRICKS prototype provided a very good proof of concept of the usefulness of the different Web 2.0 to enable CEMEX or any other company to become a learning organization. It is also important to emphasize, as mentioned from the McKinsey (2007, 2008) in this effort CEMEX focused mainly to strengthen the internal collaboration of employees in a particular business area which is BPM.

In parallel to this project, CEMEX was invited by IBM to attend the Innovation Jam, where IBM employees as well as many other knowledge workers from firms around the word attended; summing up more than 30,000 people from the five continents. The platform provided by IBM integrated the different Web 2.0 functionalities and for a limited amount of days, this network of people had access to such platform to discuss and share knowledge and contents about global business trends and opportunities (such as sustainability). For CEMEX, this latter exercise with IBM provided also a very good insight of how Web 2.0 tools work and how these functionalities can also be applied not only to increase the knowledge internally but also sharing ideas with external experts in different areas that could catalyze the company's innovation competences. This can, in fact, be an opportunity for a future collaborative project.

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Chapter 8
Real-Time Collaborative Information Management in Enterprises

Naoufel Cheikhrouhou, Michel Pouly and Sébastien Berthold

Abstract The European manufacturing sector has experienced considerable changes in the last several decades because of the reduction of the manufacturing depth. Continuous pressure on prices and global competition forced companies to concentrate on core competences, thus outsourcing most of their production activities. As a consequence, information management becomes the main important challenge for these enterprises to ensure efficient communication and material and information flows synchronization with their partners. This chapter addresses the main industrial requirements for real-time information management within the Digital Factory, identifies the corresponding shop floor information and data required, and proposes the adequate methods to automatically capture and display the data for shop floor actors.

8.1 Introduction

Information is one of the most valuable intangible resources in a manufacturing company. Underlining the importance of information is the fact that many companies invested in management software, such as Enterprise Resource Planning (ERP) or Manufacturing Execution System (MES). Such software packages are used to manage the entire company and to take several decisions at different levels: strategic, tactical, and operational. However, only few enterprises identify and use accurate data related to shop floor activities. Indeed, shop floor data are often manually captured, resulting in errors and non-up-to-date data. Manual systems for

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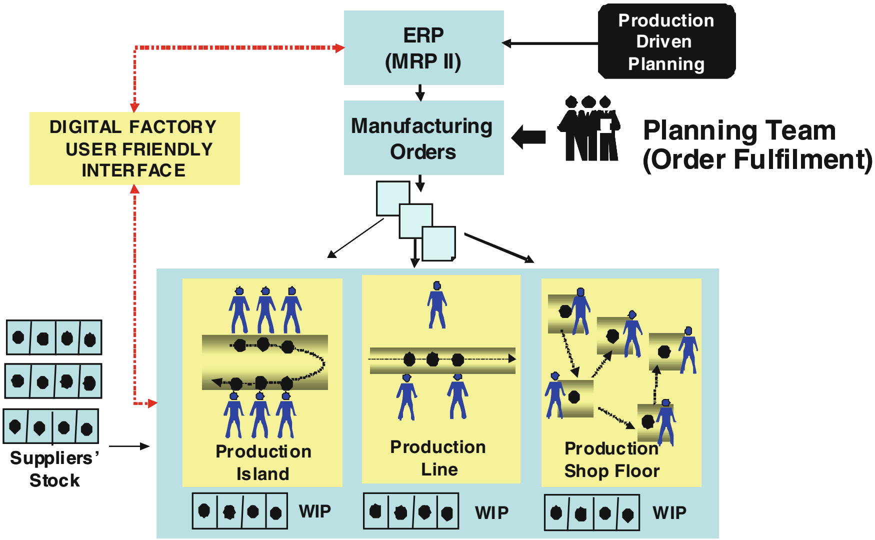


Fig. 8.1 Digital Factory at the ERP level

data collection and acquisition are time-consuming, prone to errors, and tedious. As a result, the information does not accurately and promptly reflect the real situation, and decisions are then not as efficient as expected. Consequences can be, for instance, inaccurate parts tracking, wrong status information, or even interruptions in the production process. Hence, a challenge for many companies currently is to integrate better shop floor data into management software to better manage activities and foster their competitiveness. Modern manufacturers have to be flexible and agile to answer the customers and the markets needs for individualized products and low delivery time. Moreover, pressures for cost reduction and lean manufacturing prohibit large warehouses and buffers that could lead to long delays. So, a better view of shop floor activities is a crucial point of the improvements required to reach these goals.

In the current environment, almost all companies have one or more software systems to manage their activities. Many different software editors offer solutions to manage enterprises, but they do not offer the same modules, such as MES, ERP, etc. Some softwares deal with a complete management of the enterprise (e.g., ERP), whereas others concentrate only on some specific activities, such as production planning, inventory control, etc. In this chapter, the software modules dealt with are those that address the issues related to planning and monitoring production activities and to data and information acquisition from the shop floor. Figure 8.1 shows the scope of the chapter, where production planning and control activities are considered through an ERP system (Pouly and Flores 2007). Typically, two categories of information flows are considered. The first category is related to the decisional information transmitted to the physical system via manufacturing orders. The second one is the information feedback from the shop floor to the decision-making system through user interfaces.

8.2 Enterprise Resource Planning

An ERP system is a software package dedicated to the total management of various company processes at the strategic, tactical, and operational levels (Jacobs and Weston 2007). An ERP shares, for the various entities and functions, all data necessary for management in a single database. A non-exhaustive list of the principal ERP modules is presented as follows:

- Financial management
- Management control
- Project management
- Administration of the sales
- Human resources management
- Quality management
- Production control
- Purchases management
- Supplying and stocks management

8.2.1 Manufacturing Execution System

At the workshops level, many developed functions led to data-processing applications: process scheduling, production follow-up, hours and people follow-up, quality management, statistical follow-up of quality, maintenance management, documentation management and technical data, followed corrective actions. MES is at the shop floor, what ERP is at the entire company. According to MESA International, an association grouping companies interested in the field of MES, MES software gathers the 11 following functionalities:

- Operations/detail scheduling
- Resource allocation and status
- Dispatching production unit
- Document control
- Product tracking
- Performance analysis
- Labor management
- Maintenance management
- Process management
- Quality management
- Data collection

8.2.2 Shop Floor Control

Shop floor control (SFC) is where planning meets parts. As such, it is the foundation of a production planning and control system. Because of its proximity to the actual manufacturing process, SFC is also a natural vehicle for collecting data for use in the other planning and control modules. A well-designed SFC module both controls the flow of material through the plant and makes the rest of the production-planning system easier to design and manage (Hopp and Spearman 2000). Moreover, SFC has two main functions: job dispatching and input/output control.

Job dispatching: Develop a rule for arranging the queue in front of each workstation that maintains due date integrity while keeping machine use high and manufacturing times low.

Input/output control: Monitor the work in process (WIP) and act to maintain it between the control levels. Normally, SFC software offers the following functions:

- WIP tracking
- Status monitoring
- Capacity feedback
- Quality control
- Work forecasting
- Throughput tracking

8.2.3 Enterprise Manufacturing Intelligence

The manufacturing intelligence makes it possible to produce real-time indicators for the management of the factory, to monitor the production and support improve ment and performance programs. The various functionalities of an Enterprise Manufacturing Intelligence are:

- Integration to desktop productivity tools
- Multiple time measures for trending and analysis
- Role-based dashboards with alerts
- Remote access and monitoring via portable devices

8.2.4 Current ERP Limitations

ERP systems are defined as frameworks and tools for organizing, defining, and standardizing the business processes necessary to effectively plan and control an organization. Because an ERP system covers a wide range of processes, which requires handling huge amounts of data, there are a number of shortcomings that limit the effectiveness of ERPs (Jacobs and Weston 2007):

- ERP-planning mechanisms are rather based on the use of "theoretical values" and distribution "averages" and not on the actual shop floor data and information, such as real machine workloads or current WIP. This situation can considerably influence the lead times and consequently result in producing unrealistic plans.
- The current bidirectional ERP/shop floor interfaces are very poor. The ERP is mainly a "top-down" approach where shop floor employees rarely provide on time feedback on their activities to the ERP. The "form" in which information and decisions are transferred to the shop floor is often not easy to understand for workers. Information should enable a self-organization system, increase the efficiency by reducing lead times, inventories, and WIP, and reduce the impact of replanning processes, thus allowing the shop floor to be more flexible.
- The automatic capture of production data and their transfer to ERPs can increase the competitiveness of manufacturing companies by allowing new functionalities, such as real-time inventory management and order follow-up by identifying, locating, and tracking raw materials, WIP, and finished products at the shop floor level all along the supply chain.
- It is observed that a high number of companies, including SMEs, have installed an ERP system, but only a few of them have MES or SFC solutions.

8.3 Industrial Requirements and Solutions

The European manufacturing sector has experienced considerable changes in the last 15 years because of the reduction of the manufacturing depth. In the past, most industrial companies produced almost everything in-house but the continuous pressure on the prices and the global competition forced them to concentrate on their core competences, such as engineering and final assembly as original equipment manufacturers thus outsourcing almost the whole manufacturing operations. A survey on 150 enterprises from the watch and medical appliances sector in Switzerland provides a view on the major requirements of companies working in a collaborative supply chain. Table 8.1 shows the importance of general information from the industrial point of view that could lead to better management performances. It is shown that the most important information required to efficiently run a factory is the order status, the inventory levels, and information on the available products to promise with a percentage, respectively, of 91, 91, and 87% of companies considering these requirements as important or very important. Furthermore, 91% of the addressed companies consider the orders follow-up as an important matter not only for an internal visibility but also for the partners taking part in a supply chain.

Table 8.1 Industrial requirements related the importance of information

Requirements	Very important (%)	Important (%)
Orders follow-up along the supply chain	82	9
Inventory information (work in process, raw material, components, and finished goods inventory)	74	17
Information on the available-to-promise	70	17

Indeed, the required visibility could be obtained through the data/information related to order tracking, updated inventory information, and the available products that could be promised to the different customers.

Information is a key resource for manufacturing companies and supply chains as many data must be exchanged frequently and periodically to ensure the achievement of the production planning and control activities. Because of the huge amount of produced data, it is essential to identify the most useful data and focus entirely on the origins and the use of these data:

- The "strategic data" leading to potential improvements at the supply chain level
- The "production data" leading to potential improvements at the company level, and
- The "raw data" to be captured at the shop floor level

The current production management software, such as ERP, MES, etc. does not rely on accurate and up-to-date shop floor data, as the classical manual collection is time-consuming, error prone, and not real time oriented. Major improvements are expected from an automatic capture of shop floor data.

Several research works outlined the benefits of information sharing throughout the supply chain. Sharing data, such as machine loads, sales forecasts, inventory capacities, etc. has proven, in the general case, an improvement of company and supply chain key performances such as the fulfillment rate and the production cycle time and a decrease of order fluctuations that characterizes the bullwhip effect (Croson and Donohue 2003; Chen et al. 2007). However, data sharing and integration remain a major concern as companies may use heterogeneous technical and operating systems, data management software, data models, schemas, and semantics that hinder data-sharing efficiency. In this chapter, we address the main industrial requirements highlighted in the above-mentioned survey by proposing different solutions, identifying the corresponding shop floor data required, and proposing methods to automatically capture and share these data through the supply chain.

8.3.1 Orders Follow-Up

The most important customer expectation to fulfill is to be informed, with a high degree of accuracy, on the real-time delivery schedules. In many cases, this information is important enough to motivate customers to select only suppliers that

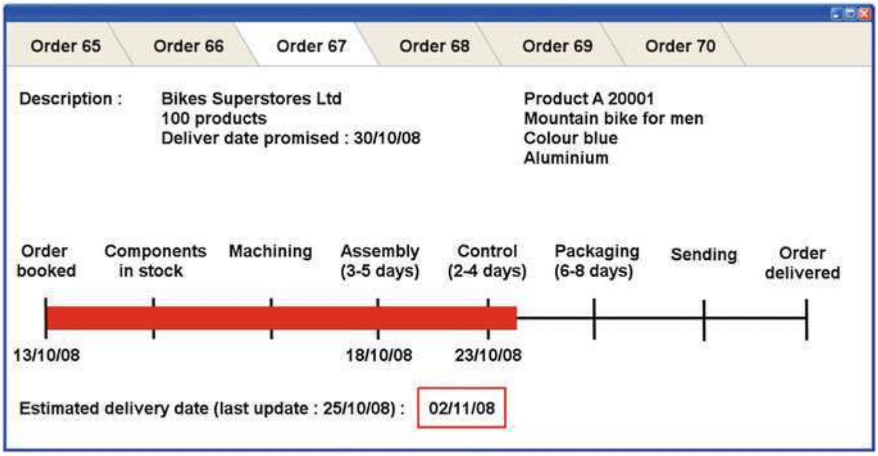


Fig. 8.2 Web-based user interface for orders follow-up

are able to provide an estimation of the delivery dates. At present, the information is not immediately available to the sales department, and sales staff must first investigate and then call back to confirm. We propose here a new (additional) user interface to seamlessly provide the authorized company's (or supply chain) collaborators with the delivery schedules by linking a Web portal to the legacy ERP systems. In that way, the required data are retrieved from the ERP database and updated constantly.

Figure 8.2 shows an example of a proposed application containing the current orders with the corresponding delivery schedules calculated using the current locations of the orders and the average actualized lead times of the remaining operations. The shop floor data required for this function are:

- Current locations and amounts of the WIP
- Lead time of each product with respect to a specific workshop
- Starting/ending time of each operation

8.3.2 Inventory Information

The inventory consists of stocks of raw materials, purchased components, parts along the manufacturing lines (WIP), and of finished goods. Inventory management is a prerequisite for calculating the available-to-promise schedules that are identified as the third most important requirement of the survey. Furthermore, because each stock item represents an investment that does not yield revenues, a lean management consists of reducing the inventory levels: "A perfect manufacturing process would have no raw material or components inventory (suppliers would deliver literally just-in-time), no finished goods inventory (deliveries to customers would also be made just-in-time), and only the minimum of WIP needed to reach the given throughput" (Hopp and Spearman 2000).

A way to decrease the inventory levels is to have accurate information on the WIP and finished goods inventory of the different suppliers to put orders just on time. Another way is to outsource the replenishment of the stock by sharing information with the suppliers. The latter then have access to the information regarding their customer's orders and the expected corresponding delivery schedules. Thus, they can manage by themselves the replenishment process. This strategy is called "vendor-managed inventory".

A WIP acts as a buffer between processes when variability or unexpected events occur, allowing a continuous manufacturing process. Different methods can be used to reduce the WIP such as the management of exceptions (for example, acting faster if a machine breaks down, if a worker is unavailable, if a tool is not at the right place, or if there is a component stockout) (Cachon and Fisher 2000).

The main function of a finished goods stock (FGS) is to reduce the delivery schedules for a product and thus it can be seen as a buffer between a company and its customers. The main solution to decrease the level of this stock is to be more responsive by decreasing all lead times. The following shop floor data are required for this function:

- WIP at each station
  - Number of parts entering the station
  - Number of parts leaving the station
- Lead time of each product
  - Arriving time in the station
  - Departure time from the station
- Supplier's delivery lead times
- Current inventory levels

8.3.3 Available-to-Promise

The main objective of a Customer Relationship Management system, as a part of an ERP module, is to better identify the customer needs to satisfy them and to attract new clients. Salesmen often promise unrealistic delivery schedules to their customers. Because customer dissatisfaction costs are estimated as high and delay penalty fees can cut the supplier's margin, realistic and updated information on the available-to-promise has to be considered. Moreover, the lack of this information is a source of tension between sales and manufacturing departments one of the surveyed companies. Here, we propose a tool connected to the company's ERP to help salesman providing realistic delivery schedules with respect to the available-to-promise.

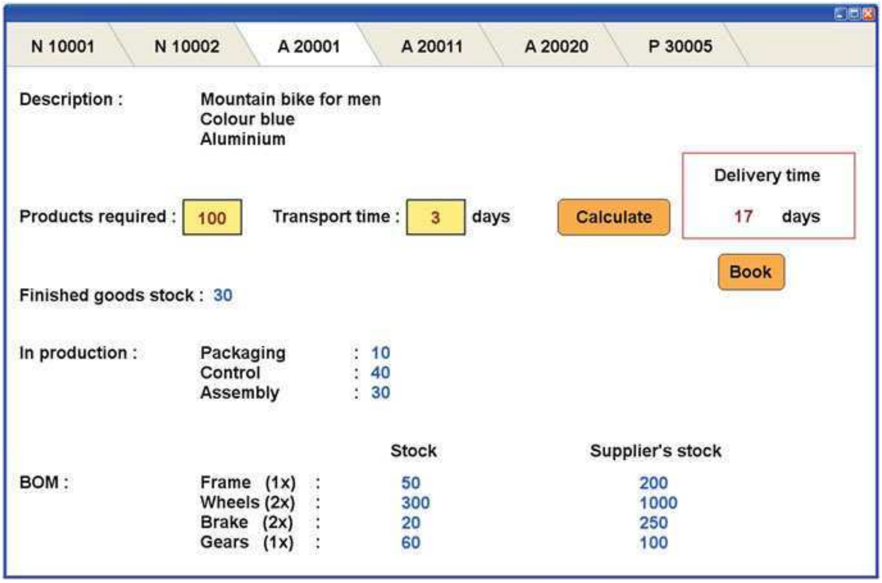


Fig. 8.3 Design of the "available-to-promise" tool

The proposed tool, for which a user interface prototype is presented in Fig. 8.3, has multiple tabs corresponding to the different products sold by the company. Each tab containing a product description, the number of available products in the FGS, the number of products currently in production that are not reserved for a specific order, and the number of each component in the stock and in the supplier's stocks. The inputs are the number of required products and the transportation time for the corresponding customer. The tool uses the following algorithm to compute the best possible updated available-to-promise realistic schedule:

1. Test if the available FGS can cover the entered number of required products.
   a. If yes, the available-to-promise schedule is set to the corresponding transportation time and the algorithm stops.
   b. If no, the number of available products is set to the value of FGS and the algorithm goes one step backward in the manufacturing line starting from the end to check how much of the remaining needs can be covered by semifinished products in this processing step. Using the bill of material, the tool calculates the corresponding lead times and adds them to the available-to-promise schedule.
2. If the needs are still not fully covered, the algorithm continues another step backward until the needs are finally covered.
3. Finally, the transportation time is added to the calculated available-to-promise schedule.

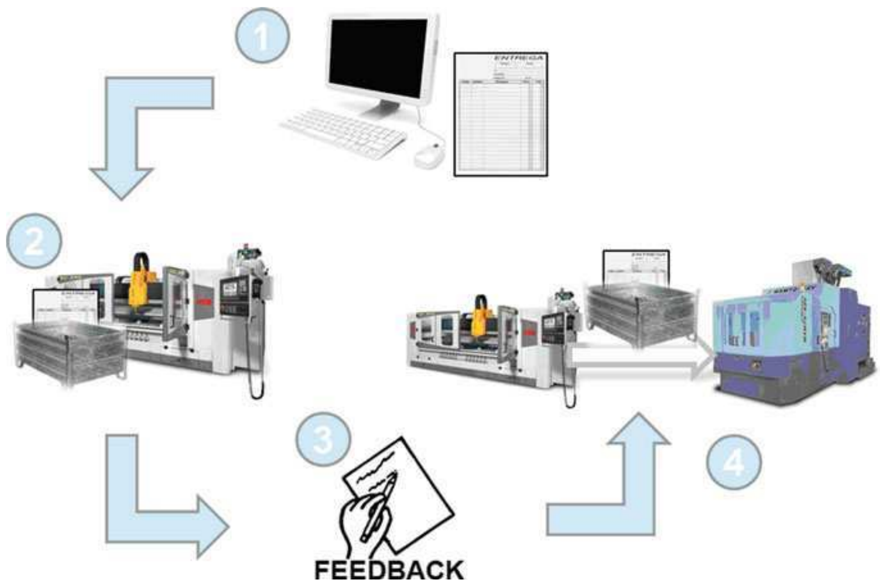


Fig. 8.4 ERP to shop floor information flows

8.3.4 ERP-to-Shop Floor Information

All enterprises to which the survey has been presented show a similar pattern of information flows management between their ERPs and the shop floors (cf. Table 8.1). This organizational production system, presented in Fig. 8.4, consists of four main phases.

- Generation of manufacturing/production orders at the ERP level
- Release of production and unstocking orders with the raw materials, components and tooling for the shop floor
- Stock-related information feedback to the ERP
- Orders follow-up and parts tracking at the shop floor level

The data structure between the different companies is very similar and includes:

- Manufacturing orders number
- Product name and reference
- Order quantity
- Components and parts
- Lot sizes
- Issuing dates and due dates
- Required tooling
- Operations list
- Operation times: setup and execution times

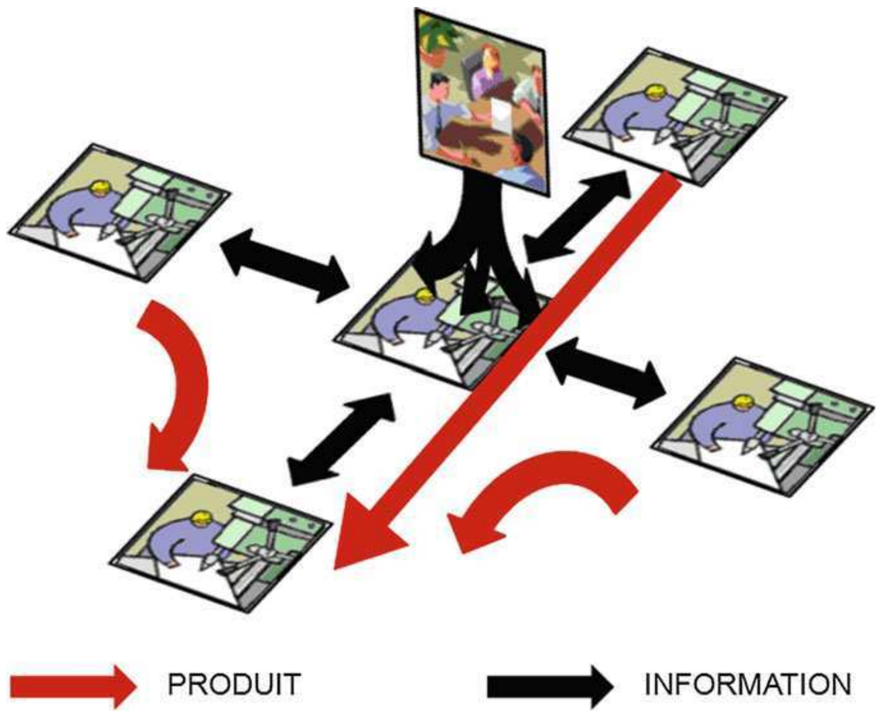


Fig. 8.5 Improved 3D ERP to shop floor data flow

All interviewed people in charge of production share the opinion that the shop floor receives enough information from the ERP to achieve the required tasks. They even fear loss of productivity and performances if the operators have access to more data than required. This symptom is called "information overload".

8.3.5 Improvement of ERP-to-Shop Floor Information Flows

It has been observed that data flows are still strongly vertical along the different hierarchy levels of the considered enterprise. On the other hand, horizontal information flows between different operational units within an enterprise are very seldom and only a few research works addressed issues of information sharing at the shop floor level (Ziegler and Dittrich 2004). Furthermore, the methods and tools used to improve the supply chain productivity could also be used at the shop floor level. Sharing information between different production units or cells, as proposed in Fig. 8.5, in addition to vertical information flows, can improve the logistic and economic performances.

Different cases could be considered to prove the feasibility of such proposal. For example:

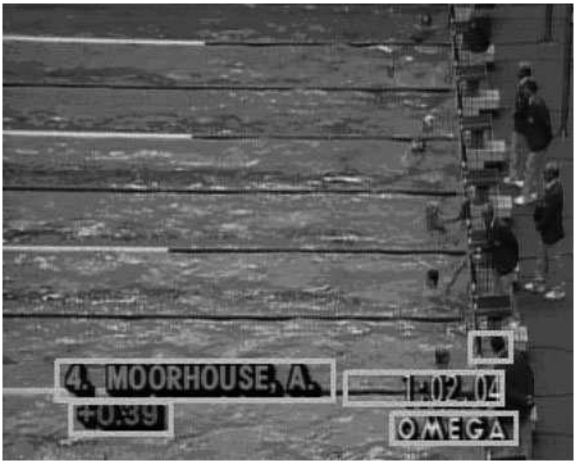


Fig. 8.6 Example of image recognition in sportive competition

- A unit achieving some production activities on a given lot can send an internal delivery schedule to the next unit allowing it to plan the machines setup and the required tooling and components in advance. The system is quite similar to a signal-controlled system.
- In the case of disturbances in a production unit, the precedent one can postpone the manufacturing activities to reduce the levels of WIP to start the production of other parts or to execute maintenance operations.

8.4 Data-Capturing Methods and Technologies

Different technologies and methods can be used to fulfill the requirements of a real-time information transmission within enterprises as well as supply chains (Udoka 1991). The most promising technologies that allow an adequate information update in quality and frequency are discussed.

8.4.1 Vision Recognition

Several industrial applications use vision recognition (Fig. 8.6). Most of the time, cameras are used in automatic production lines (or transfer lines) to monitor the production process or to count parts. However, vision is a very flexible mean to capture several types of information that can be used in different processes within the enterprises facilities or the supply chains (Abdeljaoued 2002; Medioni and Kang 2004).

8.4.1.1 Tracking

Camera vision can be used to follow the motion of an object. This application is called tracking or 3D tracking if done in three dimensions. In our case, this application can be associated with a shape recognition system to provide the location of the products in the considered system. Indeed, a product is transferred somewhere, the software recognizes its shape and tracks it to its next location. This is of course not so easy in a real case and such applications are not currently widespread.

8.4.1.2 Parts Counting

A common application used in several companies is parts counting. Camera counts the number of parts moving through its field of vision or counts the number of parts in a case. This method requires an automatic line of production or parts well classified in a case, such as bottles in a box.

8.4.1.3 Shape Recognition

Some software systems can recognize a product from its features (color, texture, shape, size, etc.) or recognize objects matching with templates stored in a technical database. Using such software allows to automatically identify products, but the result is a classification of the different parts into particular groups rather than a specific identification number, such as EPC or EAN code (EPCglobal 2006).

8.4.1.4 Presence Detection

A vision system can detect the presence of a product at a specific location. This is typically used to identify at a workstation, the products arrivals or departures (Davies 2005).

8.4.1.5 Faults Detection

Several production companies with specific automatic production lines use vision to identify faults in their products. These faults can vary from one application to another, such as looking for porosity defaults in a camshaft or for dirty mark on a can of beer. However, because faults are specific to each company and each product, this method is not well adapted for a large number of cases.

8.4.1.6 Positioning

In some cases, products have to be well positioned before beginning an operation. Cameras placed around the workstation can check if the products are well positioned and oriented. This is especially useful in automatic production line in which there are scarce manual activities.

8.4.2 Advantages and Drawbacks of Vision Recognition

8.4.2.1 Advantages

- Vision recognition is a very flexible technology that allows different applications.
- The accuracy of a vision recognition system can be close to 100% if the system is well designed.
- The "intelligence" of the system is mainly because of the software, so it is possible to update and improve the recognition system or to add some new applications through the software.

8.4.2.2 Drawbacks

- Quality of image has a key importance in a vision recognition system. So, cameras with good quality and adapted lightning are required to well recognize objects. But in some cases, it is difficult to have a good image, even with sufficient lightning and good-quality cameras. In manufacturing enterprises for instance, the environment is usually dark and it is not always feasible to add lighting to certain areas.
- Most optical character recognition (OCR) systems still have difficulties to recognize degraded documents and handwritten characters. Thus, the method consisting of scanning information from a sheet of paper cannot be implemented in a shop floor. Indeed, workers sometimes write unclearly and the sheet of paper can be degraded by harsh environments (Liu et al. 2007).
- Cameras normally generate a huge amount of data at each event occurrence. This requires communication system with a large bandwidth or a computer near the camera to treat the data before being sent to the database.
- OCR system is an expensive technology. For instance, a system gathering a camera, a computer, and software cost between 5,000 € and 12,000 €. For several workstations or for a customized application, cost can be a barrier for adopting the technology.
- Adoption of the OCR systems by employees is not trivial, because operators fear that a permanent visual-monitoring system will be used to spy on employees.

Fig. 8.7 Voice recognition application

8.4.3 Speech Recognition

The term "speech recognition" consists of the identification of spoken words as information and its transformation into data that can be used by computers. Speech recognition is a very powerful technique because it uses instinctive human senses as opposed to software (Stephenson 2003).

Indeed, such a system must be designed to interpret several types of languages, dialects, and accents as well as expressions. Industrial solutions in speech recognition are always composed of the same equipment: The user wears a headphone with a microphone and a small wearable computer that looks like a "walkman system". This wearable computer communicates with the middleware, through radio antennas, that exchanges data with ERP. The Fig. 8.7 shows a worker wearing this system used for picking in large warehouses. The employee receives some instructions about a customer's order through the headphones and confirms with the microphone when the corresponding tasks are achieved.

We can distinguish important features of a speech recognition system:

- *Speaker-dependent/speaker-independent*: Speaker-dependent systems work only with people who have a profile stored in the database. This means that each user has to create a profile before using the system at the first time. Then, the user has to load his or her profile each time a new session begins. With this method, recognition error rates are significantly reduced because the system identifies each distinctive feature of the speaker. The drawback is of course the necessity to record the voice of each user, even if recording generally takes only 20 min and the profile loaded in 1 min. Speaker-independent systems can be used by anyone. Thus, it needs no user profile leading to frequent errors of recognition compared to a speaker-dependant system.

- *Small vocabulary/large vocabulary*: The total number of words stored in the database is a key point for the design as well as the choice of the system. Some systems are called “small vocabulary”, as their database contains only about hundred of different words. If an application needs more words, a large-vocabulary system containing more of thousand words can be selected. However, the small-vocabulary system is faster and more accurate.
- *Amount of information*: The amount of information is another key factor, as its increasing information causes an increase in time and errors. Considering the small amount of information processed fulfilling the requirements, gains will be multiple in terms of labor time, data-processing time, data storage capacity, and recognition errors.
- *Environment quality*: A non-adapted environment can disrupt the quality of the signal sent to the software. In fact, if the environment is noisy, specific filtering algorithms should be implemented and a high-quality microphone is required. Moreover, hardware devices (headphone and wearable computer) should be chosen for each specific application in accordance with the temperature, the risk of impact, the noise, and the type of jobs performed by the users.
- *Type of voice in headphone*: Computers can use two different voice transmission protocols to communicate with users: “Text-to-Speech” (TTS) and “Digitized Speech”. TTS method translates data into a synthetic computer voice like in GPS or automatic call center. With TTS, the language can be chosen and the computer can translate “all data” into words. Digitized Speech is sometimes called “Record and Playback” because the computer selects a record in a database and plays it for the user. In this system, all words must be recorded by a person before using the system. Hence, users can hear a human voice, but this system needs to store all the possible sentences in databases.

8.4.4 Advantages/Drawbacks of Speech Recognition

8.4.4.1 Advantages

- Speech recognition permits multitasking. Indeed, users can achieve several manual tasks when they use the voice recognition system. This constitutes a huge time gain, because the user can send and receive information from everywhere without stopping the current task. Moreover, the risk of error or damage decreases because the operators remain concentrated on the task (Kotelly 2003).
- This system is easy to use for either skilled or non-skilled employees. No prior knowledge in computer science or signal processing is required to use a speech recognition system. This reduces the time to train new users and decreases errors because of a poor knowledge of technology.
- The implementation is easy and flexible. Some antennas must be fixed in the factory and each user must wear a headphone with a wearable computer (see Fig. 8.7). Hence, the factory organization does not have to fit to any new

organization theory and that the people do not have to take care of computers or other devices.

- Data are transferred in real time from workers to ERP and vice versa. Workers can obtain accurate data from the software and the manager can have a real-time view of activities in the shop floor. Moreover, it is the fastest way to transfer data and information from the employees to the system.
- Speech recognition is a secure technology from a technical point of view; all data are stored only in the database, and no data are available in the shop floor.
- From a human point of view, the hardware used is considered as "funny" or interesting, because it is a "new" and interactive way of working.

8.4.4.2 Drawbacks

- Noise can disrupt the system in some cases. Although there are algorithms to achieve recognition in noisy conditions, some machines in manufacturing systems make so much noise that recognition process can fail. The interference of signals between the wearable computer and antennae may also cause problems in a factory environment, because some devices have magnetic fields disturbing signal transmissions.
- This technology is not automatic and requires interventions from workers. It involves concentration and motivation from workers, although it is considered user friendly.
- There is a risk that workers will be uncomfortable talking to a computer if another person is nearby.

This technology has several potential improvements for capturing shop floor data (Trutnev 2005). Two major benefits are the small number of technical systems required for speech recognition and that this technology does not require modifying layouts (Renevey 2000). Indeed, this technology can be implemented in factories within few weeks. Moreover, although it is not an automatic technology and requires actions from workers, speech recognition is a cheap technology compared with RFID or vision recognition.

8.5 Radio Frequency Identification

In the last few years, radio frequency identification (RFID) has become a very popular technology to identify objects, following the same adoption path of the barcode 30 years ago (Oatsystems 2004; Sloan et al. 1999). Nowadays, RFID is used in many different domains, such as anti-theft protection in department stores, means of payment by card (or phone), or containers tracking solutions for global companies (Finkenzeller 2003; Khumawala et al. 2006). The aim of this section is not to discuss technical issues of RFID, but rather to deal with the use of RFID systems in a Digital Factory and discuss its advantages and drawbacks.

8.5.1 Advantages of RFID

- *Programmability*: Readers can read or/and write data onto tags.
- *Automation*: Tag data can be read and written automatically by a reader without human action.
- *Accuracy*: Because data are read without human intervention, it is less prone to errors.
- *Real time*: RFID readers can provide data from several tags at the same time and send data directly to the IT system. So, data flow is almost continuous and data can be managed in real time.
- *Storage*: A tag can safely store many different data.
- *No line of sight*: RFID tags can be read without line of sight.
- *Robustness*: Tags resist to harsh environmental conditions (dust, moisture, oils, coolants, cuttings, gases, high temperature, etc.) as they are encapsulated in material protecting them from these environments.
- *Large range of reading distances*: Reading can be done from a distance of few centimeters (LF passive tags) to several meters (UHF active tags).
- *Multitask*: Some RFID readers allow scanning a large number of tags at once.
- *Lifespan*: Tags can be reused during several years.
- *Flexibility*: RFID can be used in many different applications.

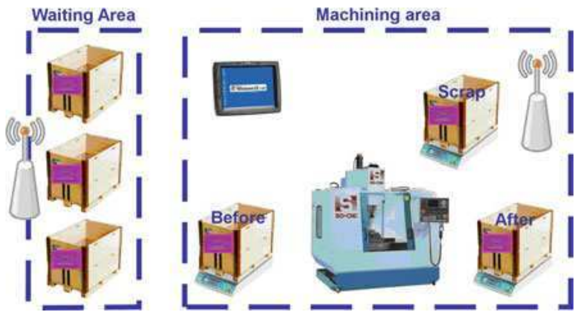
8.5.2 Drawbacks of RFID

- *Complexity*: The implementation of a RFID system is a complex task.
- *Costs*: Total costs of an RFID system implementation are relatively high, principally because the design is long and complex.
- *Adoption*: In Europe, there is currently a gap between leaders and followers in RFID adoption and this may limit the extension of RFID use.
- *Signal interference*: In some cases, radio signals used by RFID to communicate between readers and tags can produce or be subject to disturbances.
- *Amount of data*: An RFID reader produces a lot of data and these data can overflow the communication system or the database.
- *Invisible data*: Without any reader, people cannot read data stored onto an RFID tag.

8.6 Example of RFID Implementation in Shop Floors

Different implementations are possible using either fixed readers or mobile readers attached for instance to forklift trucks (Günter et al. 2008; Lu et al. 2006). We present in this section a possible implementation layout for a manufacturing

Fig. 8.8 Implementation for a manufacturing workstation



workstation as presented in Fig. 8.8. The workstation consists of pallets waiting in a specific area and a machining area where parts are machined following the sequence of operations. Two RFID readers are considered, one in the waiting area and the other one in the machining area.

1. A pallet arriving at a station is stored in the corresponding waiting area where an RFID reader periodically reads all tags to identify the available pallets. This information is sent to the middleware.
2. The operator receives the production order on his or her screen with information that allows him or her to identify the pallet(s) that need to be brought to the machining area.
3. The operator puts the pallet upstream the machine. When the weight measured by a scale reaches a certain level, the scale sends a signal to the RFID reader of the machining area through the middleware to identify the pallet and check with the order. The corresponding operation parameters are automatically downloaded from the ERP on the screen or directly into the machine control software.
4. The operator takes the first part. At this time, the weight of the pallet changes. The time between the first signal (weight reaching a certain level) and the second signal (weight change) is recorded as setup time.
5. With these events, it is possible to get the number of parts in each pallet (parts before operation, parts after operation, and scrap) and also to identify the machining time for each part.
6. When the operation is finished, the operator can enter on-screen the data that are not automatically recorded: labor time, resources used, consumables, and any additional information. Then, he or she removes the pallet of machined parts to be delivered to the next workstation. At that time, the corresponding total weight is equal to zero and a signal is sent to the middleware. This signal gives the time spent in the machining area and informs the ERP that the operation is completed.
7. The operator takes the empty pallet upstream the machine and puts it on the scale downstream the machine and gets the next order on the screen.

The raw data automatically captured in such a manufacturing workstation are represented in Table 8.2.

Table 8.2 Data and corresponding capturing method

Raw data	Capturing method
Arrival time in the waiting area	RFID reader, periodically
Departure time from the waiting area	RFID reader, periodically
Arrival time in the machining area	Scale (sends a signal to the middleware)
Departure time from the machining area	Scale (sends a signal to the middleware)
Number of parts entering the machining area	Scale (divides total weight by weight of one part)
Number of parts leaving the machining area	Scale (divides total weight by weight of one part)
Setup time	Scale (time between two signals, see point 4 of process description)
Starting operation time	Scale (signal when weight changes)
Ending operation time	Scale (signal when first pallet is empty)
Scrap	Scale (divides total weight by weight of one part)

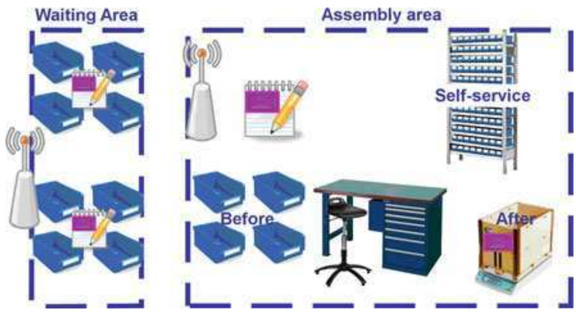


Fig. 8.9 Implementation for an assembly station

Similar studies can be undertaken to identify the process requirements for RFID implementation in an assembly system as presented in Fig. 8.9 (Zhanga et al. 2006). Different layout variations are possible for both manufacturing and assembly stations with RFID readers attached to forklift trucks, with or without scales, depending on the accuracy and aggregation of the data to be captured (see Table 8.3).

Figure 8.10 shows a possible implementation for a complete plant using mobile and fixed readers. A new technology using RFID to identify the position of a tag

Table 8.3 Assembly station raw data

Raw data	Capturing method
Arriving time in the waiting area	RFID reader, periodically
Departure time from the waiting area	RFID reader, periodically
Arriving time in the assembly area	RFID reader, periodically
Departure time from the assembly area	RFID reader, periodically
Number of parts leaving the assembly area	Scale (divides total weight by weight of one part)
Setup time	Scale (time between two signals)
Starting time of assembly operation	Manually by operator
Ending time of assembly operation	Scale (signal when first pallet is empty)

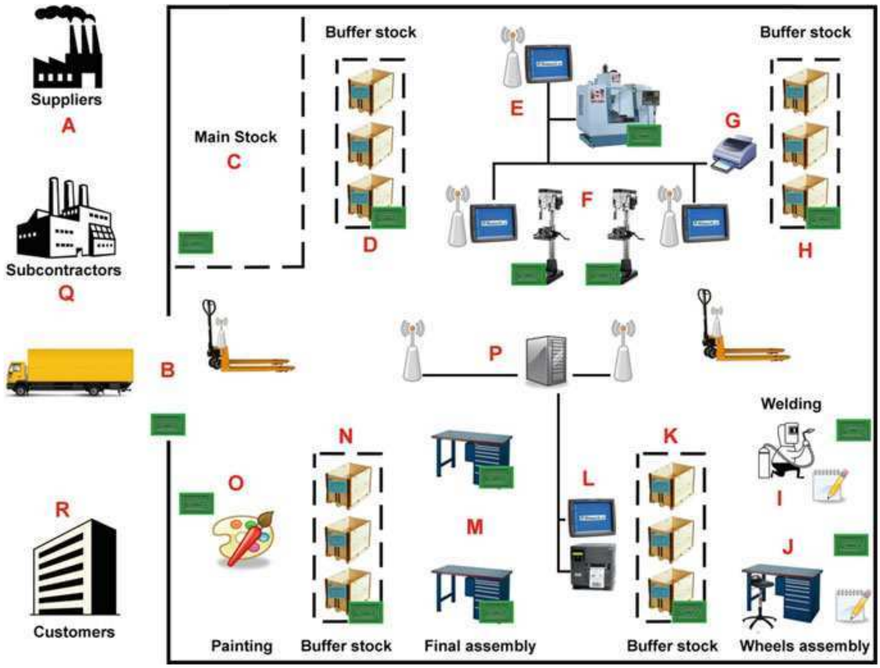


Fig. 8.10 Implementation schema for a complete plant

through triangulation (identification and localization using three readers) overcomes the current limitations, because the readers can be fixed at the ceiling and no layout modification is required.

8.7 Conclusions

Real-time collaborative information management plays an important role within the Digital Factory enabling companies as well as supply chains to fulfill the requirements of their customers. The automatic capture of shop floor data using technologies such as RFID allows a continuous monitoring of the real values of management data, making the manufacturing activities transparent for the production management system. It is also shown how the management-supporting software such as ERP provides information to the shop floor level to control the factory in an efficient way. The existence of the both information flow directions in a factory allows to control the system in a closed loop and thus, limiting the effects of perturbations and disturbances on the manufacturing performances.

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Chapter 9
The Intelligent Web

Lorenzo Sommaruga and Nadia Catenazzi

Abstract This chapter presents the concept of "intelligent web" as a synergic combination of Web 2.0 and Semantic Web technologies. In the Web evolution scenario, Web 2.0 has reached a large diffusion: the use of social networks, wikis and blogs, is now a common practice, promoting user participation and collaboration. The semantic web concept has old roots, but the application of this technology to real contexts has recently grown. Although semantic web technologies offer powerful capabilities for data formalization, integration, and query, the resulting applications are often sophisticated, difficult to use, and not intuitive. To allow the Semantic Web to achieve a widespread diffusion, there is the need to make it more user friendly, accessible, and directly useful to ordinary users. By combining the strengths of Semantic Web and Web 2.0, the intelligent web can become a reality.

9.1 Introduction

Nowadays, the World Wide Web nature is gradually changing. Two main trends influence this evolution: On one hand, Web 2.0 applications, such as social networks (Facebook and LinkedIn), wikis, and blogs, are more and more popular. They allow users to contribute to the web contents and promote participation, collaboration, and information sharing. On the other hand, emerging semantic web technologies (such as Resource Description Framework [RDF], Ontology Web

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Language [OWL], and SPARQL Protocol and RDF Query Language [SPARQL]) offer powerful capabilities for data formalization, integration, and query.

Web 2.0 and Semantic Web operate at different levels. Web 2.0 does not change the basic infrastructure of the web, but introduces new ways to use the current technology in a collaborative way. Web 2.0 is not a new version of the Web, it does not update the technical specifications, but it concerns changes in the way users and software developers use the Web (http://en.wikipedia.org/wiki/Web_2.0). While Web 2.0 is about upgrading the "frontend" and user experience of the Web, the focus of Semantic Web is about upgrading the "backend" of the Web (Spivack 2007), i.e., the underlying technology. Data are transformed into knowledge that can be automatically interpreted and processed.

Web 2.0 and Semantic Web complement each other in the way they approach content generation and structuring. Social web applications appear so far to have limited semantics, mainly based on user tagging and simple metadata, that are conceptually shared through folksonomies. Semantic web applications, on the other hand, are based on sophisticated data-handling technologies, but "lack the kind of scalable authoring and incentive systems found in successful social web applications . . . We envision a new generation of applications that combine the strengths of these two approaches: the data flexibility and portability that is characteristic of the Semantic Web, and the scalability and authorship advantages of the social web" (http://tw.rpi.edu/portal/Social_Semantic_Web:_Where_Web_2.0_Meets_Web_3.0).

As a consequence of the considerations here above, the integration of Web 2.0 and Semantic Web emerges as a great potential technology and represents the basic "ingredients" of what we call the "intelligent web". This vision considers Web 2.0 for its intuitive interaction aspects that facilitate the access not only to explicit information and knowledge but also to implicit ones.

This chapter first outlines a brief overview of the Web evolution, then it presents an introduction to the basic concepts of Web 2.0 and Semantic Web technologies, and finally, it describes the intelligent web approach as a result of the integration of the two technologies.

9.2 The Web Evolution

Web 2.0 has reached a larger and faster diffusion compared with Semantic Web. Figure 9.1 illustrates an interesting vision of the timeline of the Web, from the past to the future (Spivack 2007). It also introduces the Web x.0 term used to index the decades of the Web since 1990, where each decade is characterized by particular technologies and trends. It is worth noting that this evolution is always a gradual process where new technologies coexist with old ones. From a historical point of view, we are now between Web 2.0 and Web 3.0 era; although there are already many different semantic web applications, Semantic Web will reach a larger diffusion in the next years.

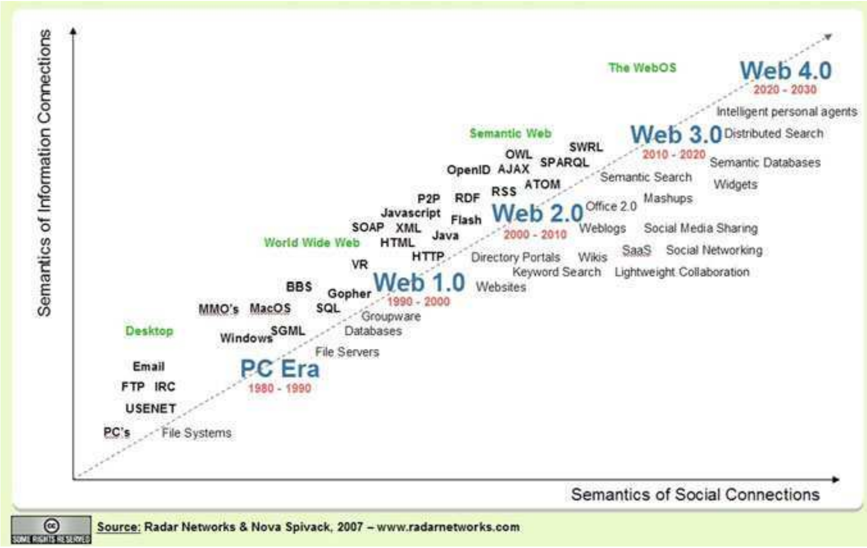

Fig. 9.1 Timeline of the past, present, future of the Web

Another similar long-term vision of the Web evolution, focused on connectivity, identifies four stages: (i) Web 1.0 (or traditional web) connecting information, (ii) Web 2.0 about connecting people, (iii) Web 3.0 about connecting knowledge, and (iv) Web 4.0 about connecting intelligence (Davis 2008). A fundamental step in this evolutionary process occurs in Web 3.0 with the transition from information-centric to knowledge-centric patterns of computing.

The importance of knowledge-centric patterns of computing is also highlighted in another vision (Davis 2008) that relates reasoning capabilities to metadata and knowledge representation. The increase of semantics enables more powerful reasoning. Thus, reasoning capabilities evolve from basic searching and discovering to semantic searching, to natural language question answering, toward smart behaviors. In other words, this determines a semantic interoperability. In this context, the focus of our interest is from Web 2.0, or social web, onward.

9.3 Web 2.0

The peculiar feature of Web 2.0 compared with Web 1.0 is that it is strongly based on user interaction. As previously said, “Web 2.0 connects people”. This shows a new trend in the use of web technologies, aiming to improve creativity, participation, collaboration, and information sharing. The user changes his or her role: From passive consumer, he/she becomes active participant, contributes to the web, and becomes an active creator of contents through the use of simple and familiar tools, such as wikis, blogs, forums, social bookmarking, etc.

The capability to collaboratively create contents and reuse existing content has required the definition of more flexible rules about the intellectual copyright protection. Creative Commons Licenses (http://creativecommons.org/) provide the copyleft alternative to the common "all rights reserved" copyright. Content creators can communicate which rights they reserve and which rights they waive for the other creators' benefit.

An interesting side effect of the active user participation, if large number of people are involved, is that users can act as a filter for what is valuable or not. In this way, users add value to existing content, a value that emerges from the consensus of many individuals (collective intelligence). A typical example is given in Amazon.com, where customer reviews give indications about the more worthy resources. "The key to competitive advantage in internet applications" becomes "the extent to which users add their own data to that which you provide" (O'Reilly 2005).

Web 2.0 includes all the applications where a high-interaction level is allowed: Systems such as Wikipedia, YouTube, Facebook, Myspace, Gmail, Google Maps, and Google Docs follow this philosophy. This kind of interaction is usually called *rich user experience*. Users go through the same level of interaction with web-based applications as they were used with desktop applications. The Web becomes a platform, and the new "software as a service (SaaS)" or "infrastructure as a service (IaaS)" approaches appear to spread among business applications.

Another interesting aspect of Web 2.0 deals with the software development "philosophy." Software is provided as a service and not as a package; software is constantly changing and users are real-time testers (the perpetual beta). In addition, software is based on open-source development practices: Users are co-developers. Even more, innovation can be achieved by assembling. When working components are available, it is possible to create value simply by assembling them in a novel way (mash-up). A final key aspect of software is that applications are increasingly data-driven. Typical examples are Yahoo!'s directory, Amazon's database of products, eBay's database of products and sellers, and Google's maps. For competitive advantage, it is crucial to own a unique hard-to-recreate source of data (O'Reilly 2005). In summary, some key points have been identified as peculiar features of Web 2.0:

- The active role of users
- Software as a service, open-source software, added value in assembling (mash-up)
- Importance of data

As appeared from the previous description, "Web 2.0 doesn't have a hard boundary, but rather, a gravitational core" (O'Reilly 2005); Web 2.0 can be thought as a set of principles and procedures visualized in the tag-cloud as shown in Fig. 9.2 (source: http://en.wikipedia.org/wiki/File:Web_2.0_Map.svg, CC Licences: Attribution-Share Alike 2.5), a typical visual representation of concepts and concept relations used in Web 2.0.

Fig. 9.2 Web 2.0 tag-cloud

9.3.1 Enterprise 2.0

The social and technical features of Web 2.0 technologies represent a rich source of business innovation. A specific term, "enterprise 2.0," has been coined to refer to the exploitation of Web 2.0 ideas and technologies by commercial and public sector organizations. The application of Web 2.0 patterns within enterprises has a number of effects (Robinson 2008):

- The cost of distributing content to a vast global audience has collapsed as content is digitalized. As a result, the number of providers of digital content has considerably increased, and consumers may quickly select exactly what they want, when they want it, online.
- Traditional approaches to marketing and advertising have reduced their influence on consumers who can benefit from the experiences of other people through consumer reviews.
- New end user applications need to be delivered more rapidly than before to be competitive in the market.
- New niche markets could be served, thanks to the reduced costs of customizing, distributing, and accessing products, content, and services enabled by Web 2.0 technologies. They involve vast number of markets that consist of small numbers of customers, perhaps distributed geographically around the world (the Long-Tail economics).

The influence of social media on the way we do business is now well known. There is a specialized blog, called "Socialnomics" (http://socialnomics.net/), that covers the latest trends in social media and their implications for users and businesses. A simple example of the potential of social media for companies is provided by Twitter: A company can get information about what is being said on a specific product or service by entering relevant brand or product terms.

9.4 The Semantic Web

Although Web 2.0 has reached a wide diffusion—it is now a common practice to share ideas and experiences using social networks and blogs, semantic web applications are typically limited in scope and impact, in spite of the "Web of data" potential. These technologies work in the "backend", making end users often not aware of the underlying complexity.

Both Semantic Web and Web 2.0 are evolutions of the Web; the transition is always gradual and never radically changes the previous situation. According to Berners-Lee et al. (2001) definition, "The Semantic Web is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation". The Semantic Web is therefore an evolution of the current Web in which computer programs as well as people can find, read, understand, and use data over the World Wide Web to accomplish useful goals on the basis of metadata and inferences rules. The Semantic Web is based on standard languages to express both data and rules to make inference on them. These languages encompass RDF for metadata representation, OWL for ontology representation, and other formats for rules representation. An important common feature of the majority of the semantic web languages is that they are based on the Extensible Markup Language (XML). Therefore, these languages inherit all the benefits of XML, including the definition of computable, self-descriptive, reusable, and non-proprietary documents.

Semantic web technologies were initially applied in research laboratories, then used by the open-source community, later on by small and specialized startups, and finally in the business context. Large companies, such as Oracle, IBM, Adobe, Yahoo, use semantic web technologies and sell complete business solutions based on Semantic Web (http://www.w3.org/RDF/FAQ). Health care and life science are currently the areas where semantic web technologies are mostly used and have demonstrated their potential. For instance, SAPPHIRE is a semantics-based health information system, developed at the University of Texas and deployed since 2004, capable of detecting, analyzing, and answering to emerging public health problems (see Feigenbaum et al. 2007).

Before going into the details of these languages, it is important to clarify which is the real advantage of the semantic web infrastructure.

Let us explain them through a couple of examples. Let us suppose you have to organize a trip from Milan to Rome by plane. You usually start consulting a number of sites, select the most useful, and mentally integrate information extracted from these different sources. To find the proper flight and accommodation, you may consult different airlines and hotel sites or you can rely on specialized sites, such as Expedia, eDreams, and TripAdvisor, that act as information aggregators. In addition, it may be worthy to consult other sites to have information about weather forecasts ("Do I need to take a jacket or only shirts?"), tourism attractions, restaurants, travel maps, etc. Although some specific sites exist to help users in this task, organizing a trip using Internet is usually a long and tedious process. Information is available in the Web but is hidden somewhere in databases, HTML or PDF documents, XML files, and Excel sheets. "Users have only access to what the Web page designers allow them to see" (Herman 2009). Semantic web technologies allow the current web to be extended to a web of data that can be directly exploited by applications. The final objective is to enable a computer program to do the same job as a human being does, combining data coming from different sources available in different formats, languages, and, sometimes, on different media reaching a semantic integration.

Another example that explains the need for a web of data in a different context deals with job offers. Let us suppose a company is looking for the most appropriate candidate to cover an open position. Internet offers several sites in different languages where people looking for a job can register and insert their CVs, and companies looking for a candidate can publish a job offer. The LinkedIn social network (http://www.linkedin.com) provides a similar service to people looking for a job and companies offering a job, additionally exploiting a recommendation mechanism. Other possibilities for companies to find a candidate for a job offer are through online newspapers. As in the travel example, the information is available in the Web using a large number of different sources, but it is codified in a way that only human beings may understand, thanks to an interpretation process. Finding and interpreting this information is a long and time-consuming task. We need to codify information in a standard way to allow machine to reason on it. Again, what we need is a web of data.

Some attempts toward this direction come from Web 2.0 applications. In some way, mash-up applications use this approach by merging contents and functionalities coming from different sources. Data from various suppliers are exposed via Web services through application-programming interfaces. An example is FlickrVision (http://flickrvision.com/), a combination of Google Maps and Flickr, to show real-time geolocated Flickr photos. RSS feeds offer another mechanism to merge contents by aggregating different information channels.

However, these are limited to provide ad hoc solutions; there is not a standard way to describe data, publish, and link them on the network. To make data machine readable, extra information should be added to describe them, the so-called metadata.

The Semantic Web provides standard technologies and languages to create this web of data, i.e., common methods to describe, query, and reason on the data and their connections. The Semantic Web defines the meaning of data (words, data records, documents, videos, images, social relationships, product listings, web pages, etc.) and provides a way to query data, reason across them, integrate, and reuse them. As mentioned above, the final goal is to allow machine to automatically process Web resources in the same way as a human being does.

To reach this objective, the first step is to create an abstract description of original data available in different formats and coming from different sources (see Fig. 9.3). This process makes data independent of their internal representation, and makes explicit the implicit knowledge. The second step consists of merging these representations. At this point, it is possible to make queries on this knowledge world (Herman 2009).

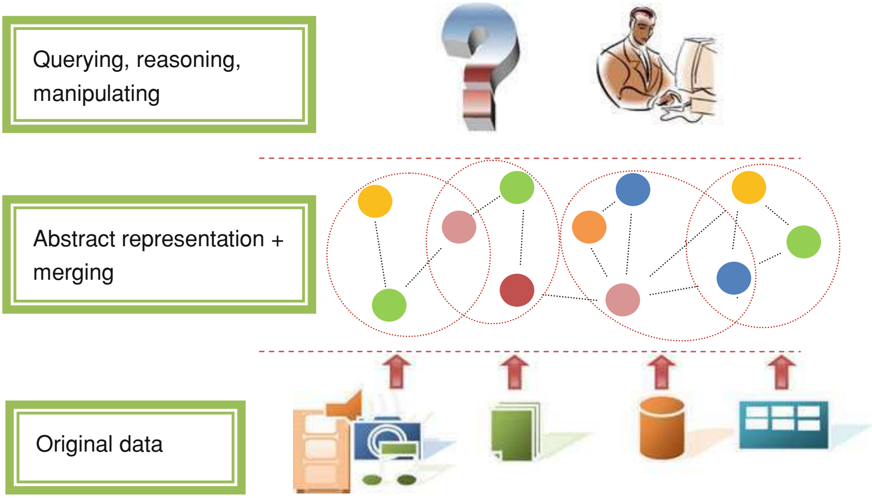

Fig. 9.3 Original data and abstract representation

The abstract representation of data is based on standard languages, such as RDF and OWL, whereas querying is carried out using the SPARQL language. The rest of this section introduces the different languages and formalisms that allow the whole process to be carried out.

9.5 Representing Data: RDF

A basic requirement to allow machines to interpret data and reason on them is to have a mechanism that enables metadata to be associated to data. That is why RDF was introduced. RDF is the basic building block of the semantic web infrastructure. It is a standard model for data interchange on the Web, and it is used to describe resources and relations among them. More specifically, the RDF model is based on three elements:

- *Resources* that can be Web pages, text documents, videos, or any other object, including not Web entities; a resource is uniquely identified by a uniform resource identifier (URI).
- *Properties* that represent characteristics of a resource; a property has a name and a value; properties are also identified by URI.
- *Statements* made of <subject, predicate, object> triples that specify the value (object) of a property (predicate) of a resource (subject). This value can be a literal or another resource.

An example of statement is

"Sommaruga is_author_of Intelligent Web" where "Sommaruga" is the subject, "is_author_of" is the predicate, and "Intelligent Web" is the object.

Other examples are

"Mary is_married_to John"
"Luke is_born_in London"
"Elisa has_age 9".

Through the statement mechanism, it is possible to specify any property of any resource in any context.

RDF statements form directed labeled graphs, where the edges represent properties of a resource, and nodes are resources or literals, i.e., values and not references to them. The graph view is the easiest possible mental model for RDF and is often used in easy-to-understand visual explanations.

Once clarified the utility of such a formalism, the question is "where does metadata come from"? There are essentially two possibilities: insert them manually or generate them automatically. Metadata can be inserted by editors and/or readers who can help to define the semantics of content by simply tagging it or can be added automatically by some software application. Obviously, this first approach is necessary in some case, for instance with non-structured data, but does not scale. The automatic generation of metadata is possible with structured or semistructured data; it can be done for instance by extracting them from HTML/XML pages (e.g., using Gleaning Resource Descriptions from Dialects of Languages—GRDDL) or from databases (for instance, Oracle can export data in RDF). GRDDL is a W3C recommendation that produces RDF from XML or XHTML documents via XSLT. Another possibility is to have metadata directly integrated into XHTML using RDFa, an extension of XHTML for embedding metadata within Web pages. It easy to extract RDF triples from RDFa documents through a simple mapping.

In conclusion, the RDF model allows structured and semistructured data to be mixed, exposed, and shared across different applications. For a more detailed description of the RDF language, good references are the W3C RDF specifications (W3C 2004a).

9.5.1 Modeling the Domain: RDFS/OWL

In RDF, it is possible to associate any property to a resource, without any constrain on values. This "freedom" makes possible to write statements that are syntactically correct but meaningless.

For instance, statements such as "9 is_author_of London" or "Mary is married_to Paris" are syntactically correct, but do not make sense. A number cannot be the author of a town, and a person cannot be married to a town. Human beings know it, machines do not.

RDF does not make assertions about the domain. That is why RDF Schema (RDFS) and OWL exist.

RDFS (W3C 2004b) and OWL (W3C 2004c; Lacy 2005) are two formalisms used to model the domain by defining the terms we can use, what restrictions apply, which relationships exist, etc. RDFS allows a vocabulary of classes and properties to be defined. A class describes a group of individuals who share common properties. Classes may be organized in hierarchies of classes and subclasses, where the inheritance principle applies.

In RDFS, it is possible to define a number of classes and relations that create constrains and limitations in the statement definitions. Concerning the examples presented above, we could define the classes "Person", "Place", and "Document" and say that "is_author_of" is a relation from "Person" to "Document", "married_to" is a relation from "Person" to "Person", and "is_born_in" is a relation from "Person" to "Place". We can also specify that "Mary" is an individual of class "Person", and "London" is an individual of class "Place". Under these constrains, statements such as "Mary is_married_to John" are correct, whereas statements such as "Mary is_married_to Paris" are not.

Therefore, RDFS defines a simple vocabulary containing the main concepts and relations useful to model a domain. To have interoperability, it is important to share a common terminology. Various vocabularies are now in the public domain. Examples of widely used vocabularies are FOAF (http://www.foaf-project.org/)—about persons, their activities, and relations to other people—and Dublin Core (http://dublincore.org/)—which includes a set of standard metadata to describe any kind of digital material.

OWL is a more powerful and expressive language to model a domain. This is the formalism officially adopted by W3C to formalize ontologies. An ontology is a conceptual schema of a domain that is formal, explicit, and shared. RDFS can be considered a simple ontology language. OWL extends RDFS by providing more capabilities: For instance, it is possible to add new classes starting from the existing ones by enumeration, restriction, intersection, etc. A distinction is made between Object Properties (i.e., relations between individuals as brother_of) and Data Properties that associate values (literals) to property (e.g., age). Another feature is the possibility to express equivalence between classes, properties, and individuals. In addition, it is possible to characterize a property by indicating that it is symmetric, functional, reflexive, inverse of another, etc. OWL expressive power allows new knowledge to be inferred starting from the existing one. For instance, if "has_father" has an inverse property that is "has_child", and it is asserted that "Thomas has_father Andrews," it is possible to automatically infer that "Andrews has_child Thomas".

OWL allows a high level of expressivity to be reached, although high expressivity means low computability. To cope with this problem, OWL offers three sublanguages that differ in their expressivity and computability:

OWL Lite: the simplest and less expressive language
OWL DL (Description Logic): more expressive than OWL Lite; it guarantees computability
OWL Full: maximum expressivity, no guarantee of a finite computation time

In conclusion, whatever language is used to model the domain (RDFS, OWL Lite, etc.), the definition of a vocabulary is useful to know how to write correct RDF statements, i.e., which properties may be defined for a specific resource, which values are allowed, etc.

9.5.2 Querying Data: SPARQL

The languages introduced so far are the basis to create the abstract representation of data, i.e., to formalize data in terms of RDF resources. Once data are formally described, it is possible to access them using SPARQL, a W3C specification to query RDF (W3C 2008). The underlying mechanism is the pattern matching, and in particular "triple pattern". An example is reported below.

Given the triples:

"Sommaruga author_of Intelligent Web"

"Catenazzi author_of Intelligent Web"

A triple pattern example is: "?name author_of Intelligent Web"

where the unbound symbol, ?name, is the subject of the triple. By applying this pattern on the triples presented above, all and only triples containing the "author_of" predicate and the "Intelligent Web" object will be extracted. In this case, both triples corresponding to the two authors.

The syntax of a SPARQL query is very similar to the SQL syntax:

```
SELECT <list of variables to be bound>
FROM <RDF resources>
WHERE {<list of triple patterns>.}
```

In general, the query returns a set of solutions; each solution provides a different value to the variables satisfying the query.

SPARQL can be used to express queries across diverse data sources, whether the data are stored natively as RDF or viewed as RDF via middleware. SPARQL is now a stable standard and it is largely used over the network. Big datasets, such as DBpedia, offer "SPARQL endpoints", i.e., SPARQL represents a "unifying point" of data coming from different sources (Herman 2009).

9.5.3 Reasoning on Data

Although there are standard languages to describe and query data, as well as to model the domain, there is not a standard language to express inference rules.

An inference rule consists of a number of premises and conclusions, where premises imply conclusions. A simple example of rule is reported below:

"A has_father B" and "B has_father C", then "A has_grand_father C"

The application of rules to a semantic world may modify the world itself by adding new relations and properties or changing the existing ones. Starting from the assertions "Charles has_father Laurence" and "Laurence has_father Thomas", the application of the rule produces that "Charles has_ grand_father Thomas", without having to explicitly assert it.

There are different formalisms to define inference rules, including Rule Markup Language (RuleML; http://www.ruleml.org/), Semantic Web Rule Language (SWRL; http://www.daml.org/2003/11/swrl/), etc. W3C is working on a new format called Rule Interchange Format (www.w3.org/2005/rules) designed to become the standard format for rules interchange in the Semantic Web.

It is worth noting that inference rules are just one mechanism to enable reasoning on the semantic world. OWL ontologies already provide knowledge that allows some sort of reasoning to be performed, without the need to have explicitly defined inference rules. This can be done for instance by exploiting ontological properties such as transitive or inverse relations.

Whatever mechanism is used to express this knowledge, we need programs capable of reasoning on the knowledge base; these programs are called reasoners. There are many aspects that characterize these programs; for instance, the algorithm used to make inference (backward or forward), the consistency check of the ontology, the support for inference rules, etc.

Examples of reasoners include: Racer, FACT++, and Pellet. A complete list of OWL or rule-based reasoners is reported in ESW Wiki (http://esw.w3.org/topic/SemanticWebTools).

9.6 The Combination of Web 2.0 and Semantic Web Into the "Intelligent Web"

As describe above, the Semantic Web provides formalisms and technologies to semantically describe data, search, and make inference on them. The resulting applications are often powerful and sophisticated but not intuitive and easy to use, because of the lack of appropriate interaction and visualization mechanisms. As mentioned above, at the moment, semantic web applications are not extensively used: There are islands of RDF resources and related ontologies in the Web, but they are not diffused on a large scale.

A remarkable exception is provided by the Linking Open Data project (http://esw.w3.org/topic/SweoIG/TaskForces/CommunityProjects/LinkingOpenData), whose goal is "to extend the Web with a data commons by publishing various open data sets as RDF on the Web" and connecting items via RDF links. This initiative currently

Fig. 9.4 The intelligent web conceptual map

involves a large number of open data sets (such as Wikipedia, Wikibooks, Geonames, WordNet, etc.), that is intended to increase in the future.

To allow the Semantic Web to achieve a widespread diffusion, there is the need to make it more user-friendly, accessible, directly useful, and valuable to ordinary users. Web 2.0 offers simple and familiar tools to bring the Web closer to the user and vice versa. The user is converted from a passive consumer to an active developer of content through a simple, customizable, and intuitive interface. By combining the strengths of Semantic Web and Web 2.0, the intelligent web can become a reality. Therefore, "intelligent web" is a synergic combination of Semantic Web and Web 2.0 technologies.

It is worth noting that there is not a commonly accepted definition of the term "intelligent web", whereas there is one for the term "web intelligence". Web intelligence is a new direction for scientific research and development that explores the fundamental roles as well as practical impacts of Artificial Intelligence and advanced Information Technology on the next generation of Web-empowered products, systems, services, and activities (http://wi-consortium.org/). According to our definition, "intelligent web" is not the same as "web intelligence", but it has a more restricted meaning.

We see the combination of the Semantic Web and Web 2.0 technologies as the key strategy to promote the collaborative development of semantics in the World Wide Web context on a large scale. Figure 9.4 shows a conceptual map of the intelligent web.

Even if Semantic Web and Web 2.0 appear competitive somehow—someone claims that folksonomies are better than semantic web taxonomies, nowadays both communities realize that these two techniques are complementary rather than competitive. The intelligent web will exist and flourish thanks to an extensive and complementary use of these two technologies.

One limitation of most of the current semantic web applications is that they are usually based on a set of predefined ontologies. The resulting environment consists of a large number of RDF resources that is possible to query and sometimes make inference on, but it does not usually allow the underlying ontologies to be modified. Although the availability of large data sets exposed in RDF is already a great achievement, these "semantic environments" are in a sense "close worlds".

Intelligent web applications will enable to do something more. Ontology creation is a hard work: It requires a good knowledge of the domain area, and usually needs a collaborative effort of different experts. "Large scale ontologies are often developed in a community" (Herman 2009). In addition, ontologies should be shared and reused. Intelligent web applications provide integrated environments, where different types of users can operate on different elements of the semantic world: the ontology (i.e., the model of the domain), the resources, the formulation of queries, the definition and application of inference rules, etc. These environments are "open". The ontology development is supported by specific tools, which enable different experts to cooperate to define a common conceptualization of the domain. The resulting model of the world is not predefined but it derives from a collaborative effort. Web 2.0 technologies can be usefully applied for this task. The traditional distinction between taxonomies, i.e., top-down classifications, and folksonomies, i.e., user-created bottom-up structures does not make sense anymore. The approach proposed here simultaneously works bottom up and top down.

Another added value coming from the use of the Web 2.0 approach is reducing the cost of knowledge creation. As previously said, RDF data can be generated automatically, from structured or semistructured data, or can be added manually. In this last case, users' tags could represent a useful mechanism to create new RDF resources, i.e., to extend the knowledge base.

To make these kinds of applications really usable, another fundamental requirement is to provide user-friendly interfaces and rich user-experiences. The lesson learned by Web 2.0 applications can provide useful clues. In addition, visualization techniques must be widely applied to provide an intuitive representation both of the domain model (ontology) and of resources and their relations. From a study of ontology development (Gaševic et al. 2006), it emerges that users require intuitive and simple mechanisms that can be used directly by domain experts, who have knowledge and competencies to create the conceptualization of the domain, rather than by ontologists. "To facilitate the process of ontology editing, a higher abstraction level of the ontology constructs is required. The ontology constructs must be expressed in a more intuitive and powerful way, by means of a visual interactive representation that is a simplification of the world, reducing, where necessary and possible, complexity without losing completeness" (Catenazzi et al. 2009). Intuitive graphical representations are also useful to represent the set of resources, opportunely filtered and organized.

9.7 Conclusion

In conclusion, intelligent web applications are open environments to create, modify, and query both the model of the domain and the world of resources, thanks to the synergy of Semantic Web, Web 2.0, and advanced visualization and interaction techniques. Semantic Web provides the underlying infrastructure to support data description, search, and reasoning. Web 2.0 offers simple and familiar tools to bring user closer to the web of data and convert him/her in an active participant. Visualization techniques are here exploited to provide an effective way to present both ontologies and resources in intuitive ways.

Intelligent web applications answer to the increasing need for tools to support knowledge elicitation, formalization, and sharing. Part IV of this book provides different case studies that demonstrate the potential of intelligent web technologies in the enterprise context.

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Part III
Production Systems Modelling, Simulation and Visualization

Chapter 10
Human Body Modeling

Joung Hwan Mun and Yong Hoon Rim

Abstract This chapter is devoted to the development and usage of digital human models. Digital human models have been used to simulate human postures and motions with the aim to predict realistic human postures and motion trajectories in given industrial working scenarios. Therefore, many research groups have been developing digital human modeling (DHM) tools to evaluate human working conditions, such as eM-Human, Safework, Jack, 3DSSPP, Lifemodeler, and so on. However, they also have technical challenges to automatically generate postures/motions of digital human models and to improve the accuracy of DHM simulation results, because the motion generation procedure including manual posturing is too complex and time-consuming even for simple reaching postures and the accuracy of the generated motions is not sufficient for complex human tasks in dynamic working conditions. Therefore, in this chapter, we introduce two different human-modeling methods for DHM simulation, which are task-based modeling to simplify the motion generation procedure and inverse dynamic modeling to analyze human motion more accurately, with the aim of presenting novel ways to achieve those technical challenges.

10.1 Introduction

Digital human modeling (DHM) simulation is to predict realistic human postures and motion trajectories for given industrial working scenarios. However, human posture and motion prediction is a difficult problem to solve, because human body has many degrees of freedom (DOFs) that require huge amount of computation for

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simulating the postures and motions. Therefore, to solve the difficult problem, several kinds of human modeling methods have been developed, such as task-based modeling methods and the inverse dynamic modeling method using 3D motion capture systems.

Task-based modeling methods aim to generate realistic human motion automatically without any complex and time-consuming processes, and can be classified into two categories: the data-based and non-data-based modeling approaches. The data-based modeling method predicts realistic human postures and motions by modifying relevant motion samples from a huge amount of real human motion dataset. In this case, it requires creations of a large human motion database through motion capture experiments, which are complex and time-consuming. Therefore, in this chapter, we will be focused on the task-based modeling method accompanied with a non-data-based modeling approach using optimization techniques.

Even through the task-based modeling method has a strength that is easy to generate human postures and motions, however, it does not guarantee realistic human postures and motions. Therefore, there is a clear need to apply the inverse dynamic modeling method using 3D motion capture systems to DHM simulation with real human postures and motions.

The inverse dynamic modeling method is commonly used in the field of biomechanics. Especially, it refers to the study of joint forces, moments, and the effects of the actions on human body musculoskeletal structures. The joint kinetic information can be used to evaluate human working conditions in the aspects of injury biomechanics of the ligaments, cartilage, menisci, and bones forming human joints. In addition, the method guarantees relatively accurate analysis results calculated by real human postures and motions, because it is based on experimental tests. The inputs, outputs, strength, and weakness of each modeling method are presented in Table 10.1.

Table 10.1 Characteristics of each modeling method

	Task based Modeling (non-data-based modeling)	Inverse dynamic Modeling (data-based modeling)
Inputs	Anthropometry information	Anthropometry information
	Target location/orientation	Markers' trajectories
	Human location/orientation	Ground reaction forces
Outputs	Joint trajectories	Joint trajectories
	Joint absolute angles	Joint absolute angles
	Joint relative angles	Joint relative angles
		Joint forces, moments and powers
Strength	Easy to generate human postures and motions	High accuracy in DHM simulation
		Applicability for complex motions
Weakness	Low accuracy in DHM simulation	Experimental setup in the real world
	Applicability for simple-reaching motions	

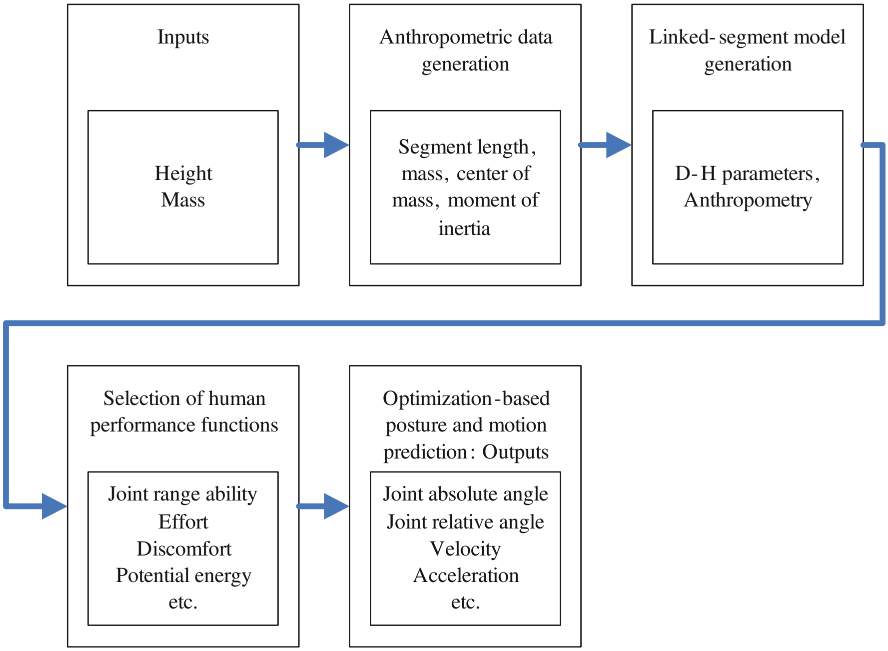

Fig. 10.1 Workflow of the optimization-based human posture and motion prediction

In industrial cases, workers perform manual tasks mostly based on upper-body motions, including the joint between lumbar 5th and sacral 1st segments. In addition, most of work-related musculoskeletal disorders are caused by exaggerative postural loading of human upper body. Therefore, in this chapter, the scope of discussion is limited within human upper-body modeling.

10.2 Task-Based Modeling of Human Upper Body

Task-based modeling method is composed of four major processes: the anthropometric data generation, the linked-segment model generation, the selection of human performance functions, and the optimization-based posture and motion prediction (Fig. 10.1). The anthropometric data generator calculates the length, mass, center of mass, and moment of inertia of each body segment. Given anthropometric data, the linked-segment model generator creates a human upper-body model using Denavit–Hartenberg (DH) method (Denavit and Hartenberg 1955). The next processor selects the human performance functions as the object functions for the optimization formulation. Using the object functions, the final processor performs the optimization-based posture and motion prediction using constrained optimization techniques. More detail about the processes is discussed in each subsection.

10.2.1 Anthropometric Data Generation

The anthropometric data generation aims to represent the different sizes and shapes of the human body segments to design workplaces and human-oriented products in the field of industrial ergonomics. In general, most of the commercial DHM tools provide the preexisting anthropometric databases, which include the following five groups: very small (5th percentile), small (25th percentile), medium (50th percentile), tall (75th percentile), and very tall (95th percentile). However, they are mainly on the segmental lengths, because these data can be easily attained, and the others, such as center of mass, moment of inertia, and mass, are difficult to obtain (Shan and Bohn 2003). Therefore, Shan and Bohn (2003) have established regression equations to calculate several human anthropometric datasets, including those depend on gender, race, body height, and body mass. In this subsection, we introduce sample regression equations to calculate anthropometric datasets for Asian female. For the anthropometrical data and coefficients of regression related to gender and race, you can refer the study by Shan and Bohn (2003). Tables 10.2, 10.3, and 10.4 present the regression equations to calculate the mass, length, and moment of inertia properties using the subject's height and mass, respectively. Table 10.5 presents the location of segmental center of mass.

10.2.2 Linked-Segment Model Generation

To generate linked-segment model of human upper body, we need to discuss how to describe the kinematic relationship between a pair of adjacent links, because the relative motion of adjacent links is caused by the motion of the joint connecting two links. One of the most effective methods to describe the kinematic relationship between a pair of adjacent links is the DH method. It has been used to describe the translational and rotational relationships between adjacent links effectively (Yamaguchi 2001; Craig 2005). Its strength is in handling large numbers of DOFs using a minimum number of parameters to completely describe the kinematic relationship between two adjacent links. The relative location of the two coordinate

Table 10.2 Regression equation to calculate the mass property of each segment

Property	
Segment	Segment mass
Head	$0.638 + 0.0293 \times \text{mass} + 0.0172 \times \text{height}$
Upper-trunk	$-11.7 + 0.297 \times \text{mass} + 0.0461 \times \text{height}$
Mid-trunk	$5.44 + 0.186 \times \text{mass} - 0.0546 \times \text{height}$
Lower-trunk	$2.21 + 0.101 \times \text{mass} - 0.0086 \times \text{height}$
Upper-arm	$0.254 + 0.0265 \times \text{mass} - 0.0033 \times \text{height}$
Fore arm	$-0.625 + 0.0083 \times \text{mass} + 0.0054 \times \text{height}$
Hand	$-0.605 + 0.0022 \times \text{mass} + 0.0044 \times \text{height}$

Table 10.3 Regression equation to calculate the length property of each segment

Property	
Segment	Segment length
Head	−9.14 − 0.126 × mass + 0.244 × height
Upper-trunk	−29.5 + 0.0996 × mass + 0.328 × height
Mid-trunk	26.7 + 0.132 × mass − 0.125 × height
Lower-trunk	38.2 + 0.105 × mass − 0.130 × height
Upper-arm	−10.6 − 0.102 × mass + 0.246 × height
Fore arm	−4.035 − 0.0287 × mass + 0.173 × height
Hand	−5.66 − 0.0058 × mass + 0.143 × height

Table 10.4 Regression equation to calculate the moment of inertia property of each segment

Property		
Segment	Segment moment of inertia	
Head	*X* axis	−243 + 2.86 × mass + 2.14 × height
	Y axis	−362 + 2.874 × mass + 3.091 × height
	Z axis	78.6 + 2.22 × mass − 0.129 × height
Upper-trunk	*X* axis	−3900 + 54.8 × mass + 14.5 × height
	Y axis	−3504 + 40.4 × mass + 14.5 × height
	Z axis	−1420 + 43.8 × mass + 0.528 × height
Mid-trunk	*X* axis	962 + 23.3 × mass − 11.3 × height
	Y axis	586 + 11.8 × mass − 6.14 × height
	Z axis	586 + 24.1 × mass − 9.10 × height
Lower-trunk	*X* axis	197 + 14.0 × mass − 2.86 × height
	Y axis	21.6 + 8.53 × mass − 0.788 × height
	Z axis	248 + 19.9 × mass − 5.08 × height
Upper-arm	*X* axis	−90.1 + 0.875 × mass + 0.611 × height
	Y axis	−88.9 + 1.04 × mass + 0.560 × height
	Z axis	8.31 + 0.483 × mass − 0.154 × height
Fore arm	*X* axis	−79.6 + 0.365 × mass + 0.541 × height
	Y axis	−76.5 + 0.340 × mass + 0.523 × height
	Z axis	−5.16 + 0.0946 × mass + 0.0221 × height
Hand	*X* axis	−10.4 + 0.0422 × mass + 0.0645 × height
	Y axis	−11.5 + 0.0572 × mass + 0.0696 × height
	Z axis	−3.37 + 0.0300 × mass + 0.0170 × height

frames attached to the adjacent link can be determined by four parameters θ_i, d_i, a_i, and α_i. These parameters typically entered into a table defined as the DH table.

Figure 10.2 presents a pair of adjacent links and their associated joints. Line H_iO_i is the common normal to joint axes i and $i+1$. The origin of the ith coordinate frame O_i is located at the intersection of joint axis $i+1$ and the common normal between joint axes i and $i+1$. The frame of link i is at joint $i+1$ rather than at joint i. The x_i axis is directed along the extension line of the common normal, while the z_i axis is along the joint axis $i+1$.

Table 10.5 Segmental center of mass expressed in percentage of segmental length

Property	
Segment	COM location (%)
Head	39.4
Upper-trunk	59.3
Mid-trunk	49.3
Lower-trunk	42.9
Upper-arm	45.0
Fore arm	43.2
Hand	35.8

In Fig. 10.2,

- θ_i is the included angle of axes x_{i-1} and x_i;
- d_i is the distance between the origin of the coordinate system $x_{i-1}y_{i-1}z_{i-1}$;
- a_i is the distance between the two common perpendicular lines; and
- α_i is the included angle of axes z_{i-1} and z_i.

With these four parameters, the transformation matrix can be defined as $T_{(i-1)i}$

$$T_{(i-1)i} = \begin{bmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & \alpha_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & \alpha_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (10.1)$$

The matrix method can be used to derive the kinematic equations of the linkage. If the mechanical system has n links, we can have:

$$T = T_{01}T_{12}, \ldots, T_{(n-1)n} \quad (10.2)$$

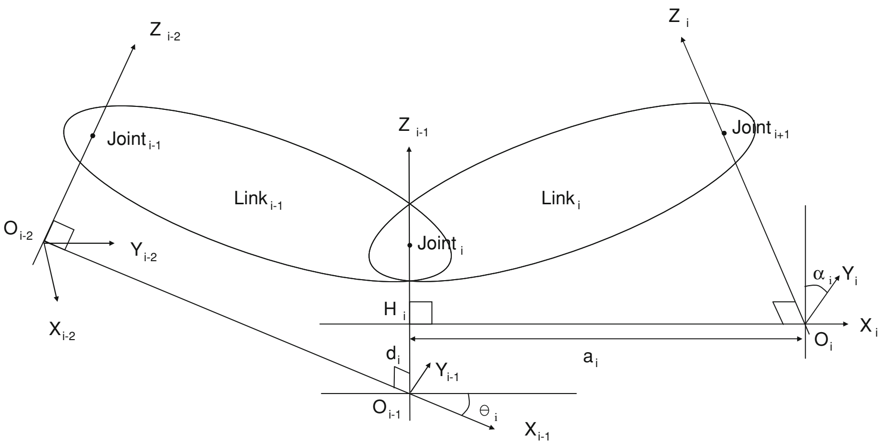

Fig. 10.2 The Denavit–Hartenberg notation

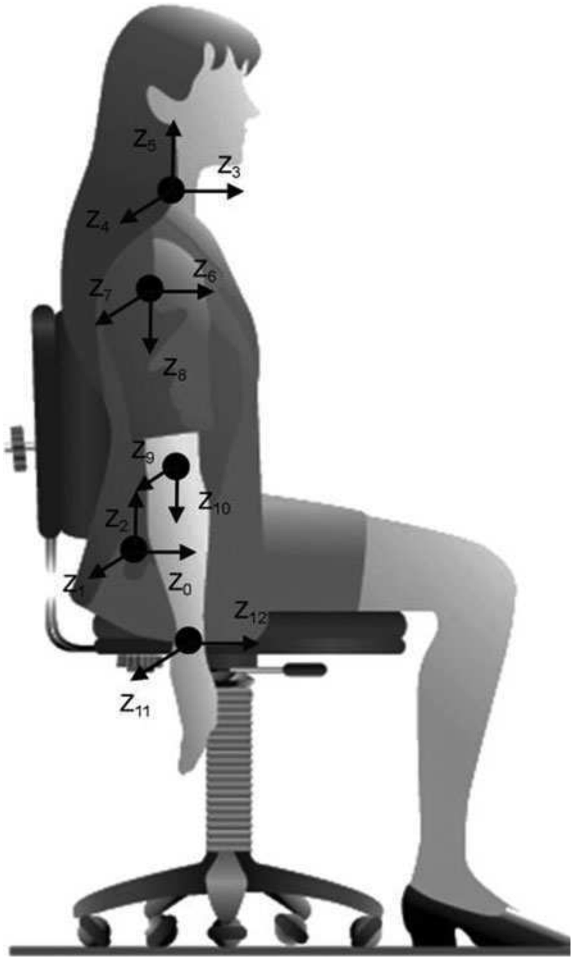

Fig. 10.3 Configuration of the upper-body linked segment model

For an example using the DH method, consider the upper-body model comprising the lumbar-sacral joint (3DOFs), neck joint (3DOFs), shoulder joint (3DOFs), elbow joint (2DOFs), and wrist joint (2DOFs) as shown in Fig. 10.3 and Table 10.6. In the Table 10.6, L_i ($i = 1, 2, 3, 4$) presents the segment lengths of human upper body (Flash and Hogan 1984; Abdel-Malek et al. 2006). In addition, regarding the joint anatomical motion, joint 1 corresponds to lateral bending, joint 2 corresponds to flexion/extension, and joint 3 corresponds to axial rotation of the human trunk. Joint 4 corresponds to lateral bending, joint 5 corresponds to flexion/extension, and joint 6 corresponds to axial rotation of the human head. Joint 7 and 14 corresponds to flexion/extension, joint 8 and 15 corresponds to abduction/adduction, and joint 9 and 16 corresponds to medial/lateral rotation of shoulder joints. Joint 10 and 17 corresponds to flexion/extension, and joint 11 and 18 corresponds to internal/external rotation of elbow joints. Joint 12 and 19 corresponds to abduction/adduction, and

Table 10.6 Denavit–Hartenberg table for 13DOFs upper-body model (refer to the Fig. 10.3)

	θ_i	d_i	α_i	a_i
Joint 1	$\pi/2 + \theta_1$	0	$\pi/2$	0
Joint 2	$\pi/2 + \theta_2$	0	$\pi/2$	0
Joint 3	$\pi/2 + \theta_3$	L1	$\pi/2$	0
Joint 4	$\pi/2 + \theta_4$	0	$\pi/2$	0
Joint 5	$\pi/2 + \theta_5$	0	$\pi/2$	0
Joint 6	$-\pi/2 + \theta_6$	0	$-\pi/2$	L2
Joint 7	θ_7	0	$\pi/2$	0
Joint 8	$\pi/2 + \theta_8$	0	$\pi/2$	0
Joint 9	$\pi/2 + \theta_9$	L3	$\pi/2$	0
Joint 10	$\pi/2 + \theta_{10}$	0	$\pi/2$	0
Joint 11	θ_{11}	0	$\pi/2$	L4
Joint 12	$-\pi/2 + \theta_{12}$	0	$-\pi/2$	0
Joint 13	$\pi/2 + \theta_{13}$	0	$\pi/2$	0

joint 13 and 20 corresponds to flexion/extension of wrist joints (Fig. 10.3 and Table 10.6). Using the defined DH table, we can easily derive the kinematic equations of the upper-body linked segment model (Eq. 10.3).

$$T_{01}=\begin{bmatrix}\cos(\pi/2+\theta_1) & -\sin(\pi/2+\theta_1)\cos\alpha_1 & \sin(\pi/2+\theta_1)\sin\alpha_1 & \alpha_1\cos(\pi/2+\theta_1)\\ \sin(\pi/2+\theta_1) & \cos(\pi/2+\theta_1)\cos\alpha_1 & -\cos(\pi/2+\theta_1)\sin\alpha_1 & \alpha_1\sin(\pi/2+\theta_1)\\ 0 & \sin\alpha_1 & \cos\alpha_1 & d_1\\ 0 & 0 & 0 & 1\end{bmatrix}$$

$$T_{12}=\begin{bmatrix}\cos(\pi/2+\theta_2) & -\sin(\pi/2+\theta_2)\cos\alpha_2 & \sin(\pi/2+\theta_2)\sin\alpha_2 & \alpha_2\cos(\pi/2+\theta_2)\\ \sin(\pi/2+\theta_2) & \cos(\pi/2+\theta_2)\cos\alpha_2 & -\cos(\pi/2+\theta_2)\sin\alpha_2 & \alpha_2\sin(\pi/2+\theta_2)\\ 0 & \sin\alpha_2 & \cos\alpha_2 & d_2\\ 0 & 0 & 0 & 1\end{bmatrix}$$

$\ldots$

$$T_{1213}=\begin{bmatrix}\cos(\pi/2+\theta_{13}) & -\sin(\pi/2+\theta_{13})\cos\alpha_{13} & \sin(\pi/2+\theta_{13})\sin\alpha_{13} & \alpha_{13}\cos(\pi/2+\theta_{13})\\ \sin(\pi/2+\theta_{13}) & \cos(\pi/2+\theta_{13})\cos\alpha_{13} & -\cos(\pi/2+\theta_{13})\sin\alpha_{13} & \alpha_{13}\sin(\pi/2+\theta_{13})\\ 0 & \sin\alpha_{13} & \cos\alpha_{13} & d_{13}\\ 0 & 0 & 0 & 1\end{bmatrix}$$

$$T = T_{01}(\theta_1)T_{12}(\theta_2),\ldots,T_{1213}(\theta_{13}). \tag{10.3}$$

10.2.3 Selection of Human Performance Functions

As mentioned previously, to formulate the optimization-based human posture and motion prediction, the human performance functions should be mathematically defined and selected as the object functions for the optimization formulation. For this purpose, we introduce several kinds of human performance functions in this subjection. Those human performance functions have been employed to quantify the natural human joint motion in previous studies (Jung et al. 1995, 1996; Abdel-Malek et al. 2006).

10.2.3.1 Joint Range Availability

Joint range availability (JRA) minimizes the possibility that a joint will reach a biomechanical stop, in other words, a joint will fall outside the range of motion (Jung et al. 1995). The weight w_i is to reflect anthropometric characteristics of human upper body.

$$\mathrm{JRA} = \sum_{i=1}^{n} w_i \sqrt{((\theta_i - \theta_{i\_\mathrm{central}})/\nabla\theta_i)^2}. \tag{10.4}$$

In this equation:

- θ_i is the ith joint angle to be obtained;
- $\theta_{i\_\mathrm{central}}$ is the center angle of the ith joint, which indicates the central position of each joint;
- w_i is the weight of each joint assigned through simulation; and
- $\Delta\theta_i$ is the maximum angular displacement of the ith joint.

10.2.3.2 Joint Effort

Joint effort (JE) is defined as the displacement of each joint from its initial position. Therefore, JE depends on the initial configuration of the upper body (Abdel-Malek et al. 2006). The weight w_i is to reflect anthropometric characteristics of human upper body.

$$\mathrm{JE} = \sum_{i=1}^{n} w_i \sqrt{(\theta_i - \theta_{i\_\mathrm{initial}})^2}. \tag{10.5}$$

In this equation:

- θ_i is the ith joint angle to be obtained;
- θ_{ci} is the initial angle of the ith joint, which indicates the initial position of each joint; and
- w_i is the weight of each joint assigned through simulation.

10.2.3.3 Joint Discomfort

Joint discomfort (JD) is to measure the discomfort level from the neutral position of each joint. It is defined as a displacement of each joint from its neutral position.

Similar to the JRA, weight w_i is to reflect anthropometric characteristics of human upper body.

$$\mathrm{JD} = \sum_{i=1}^{n} w_i \sqrt{(\theta_i - \theta_{i\_\mathrm{neutral}})^2} \tag{10.6}$$

In this equation:

- θ_i is the ith joint angle to be obtained;
- $\theta_{i\_\mathrm{neutral}}$ is the neutral angle of the ith joint, which indicates the neutral position of each joint; and
- w_i is the weight of each joint assigned through simulation.

10.2.3.4 Potential Energy

Potential energy (PE) is defined as the sum of each segmental potential energies P_i. To determine the position and orientation of the upper body segments, the transformation matrices ${}^{(i-1)}A_i$ is defined (Abdel-Malek et al. 2006). For upper-body kinematic chain, the total potential energy can be written by

$$\mathrm{PE} = \sum_{i=1}^{n} P_i = \sum_{i=1}^{n} \left(-m_i g\left({}^0A_i^i r_i\right)\right). \tag{10.7}$$

In this equation:

- m_i is the ith segment mass;
- g is the gravity vector; and
- ${}^0A_i$ is 4×4 transformation matrix.

10.2.4 Optimization-Based Human Posture and Motion Prediction

To perform the optimization-based human posture and motion prediction, the anthropometrical data, the linked-segment model, and the objective functions are required. In addition, we should also define constraint conditions for the optimization formulation. The following contains the constraints and the theoretical foundation to generate human postures and motions using constrained optimization technique (Cappello et al. 1996; Rao 1996; Abdel-Malek et al. 2006; Yang et al. 2006).

10.2.4.1 Constraints

There are two constraints for human posture and motion generation. The first one is related to the point on the end-effecter determined by $P_{\text{end-effecter}} = [x\ y\ z]^T$, because the difference between $P_{\text{end-effecter}}$ and $P_{\text{target-point}}$ must be set within a specified tolerance ε (e.g., 0.0001). The other one is with regard to the joint upper and lower limits, because different joints have their own joint movement ranges.

$$P_{\text{end\_effecter}} - P_{\text{target}} \leq \varepsilon$$

$$\theta_i^{\text{lower\_bound}} \leq \theta_i \leq \theta_i^{\text{upper\_bound}} \quad i = 1, 2, 3, \ldots, n$$

10.2.4.2 Optimization Formulation for Human Posture and Motion Generation

In this subsection, we introduce the optimization algorithm proposed in previous study to generate optimum motion along a path using polynomial joint trajectory (Abdel-Malek et al. 2006). There are three steps to generate optimum motion of the human upper body.

1. Posture prediction at the initial and final target points:

   Find: $\boldsymbol{q} = \{q_i | 1 \leq i \leq n\}$
   to minimize: discomfort, displacement, effort, etc.
   subject to:
   $\left|\left|\boldsymbol{P}_{\text{end-effector}}(\boldsymbol{q}) - \boldsymbol{P}_{\text{target}}\right|\right|^2 \leq \varepsilon$ (distance constraint)
   and $q_i^{\text{Lower}} \leq q_i \leq q_i^{\text{Upper}}$ (joint limits).

2. External trajectory generation.
3. Motion prediction using the generated external trajectory:
   Optimum motion along a path using polynomial joint trajectories is determined by solving the following optimization equation:

   Find: $\boldsymbol{q}(t) = \{q_i(t) | 1 \leq i \leq n\}$
   to minimize: discomfort, etc.
   subject to:
   $\left|\left|\boldsymbol{P}_{\text{end-effector}}(\boldsymbol{q}(t_j)) - \boldsymbol{P}_{\text{target}}(t_j)\right|\right|^2 \leq \varepsilon$ (distance to path)
   and $q_i^{\text{Lower}} \leq q_i(t) \leq q_i^{\text{Upper}}$ (joint limits)

For this equation, the *feasible space* is defined as the set of all solutions $\boldsymbol{q}(t)$ for which every constraint is satisfied.

10.3 Inverse Dynamic Modeling of Human Upper Body

As mentioned in previous subsection, the joint kinetic information can be used to evaluate human working conditions in the aspects of injury biomechanics of the human joints. In addition, the inverse dynamic modeling method using 3D

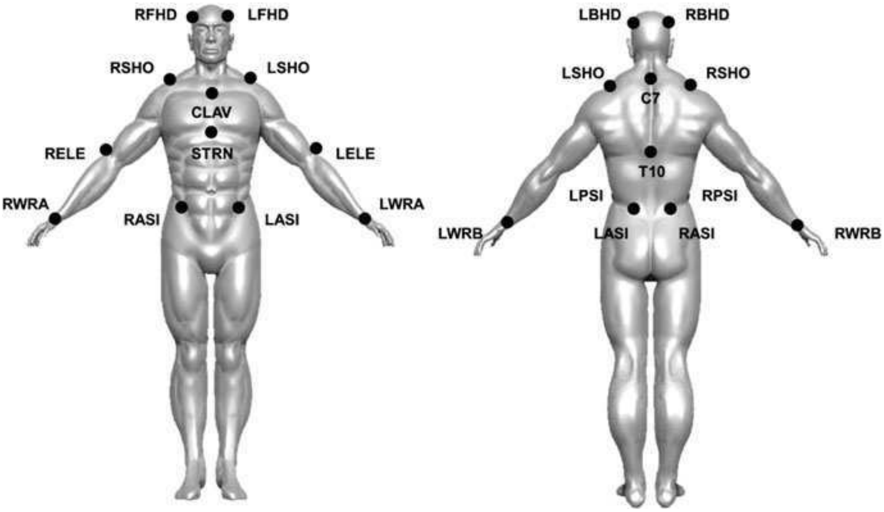

Fig. 10.4 Skin marker sets for human upper-body motion analysis

motion capture systems guarantees relatively accurate analysis results calculated by real human postures and motions, because it is based on experimental tests. Therefore, in this subsection, we introduce the inverse dynamic modeling method. The inverse dynamic modeling method requires several steps that are the preanalysis procedure for the selection of a reference system and the application of an effective error reduction method, and the actual analysis procedure for the joint kinematic and kinetic analyses. However, the application of an effective error reduction method is not introduced in this subsection, because it is a specified research area in accurate movement analysis. Therefore, we present the experimental test procedure, including the skin marker setting, the selection of a reference system, and the actual analysis procedure in this subsection.

10.3.1 Preanalysis Procedure

10.3.1.1 Skin Marker Sets

There are two marker sets commonly used in the movement analysis, which are Cleveland Clinic marker set and Helen Hayes marker set. In this subsection, we introduce the upper-body skin marker system based on the modified Helen Hayes marker set. Figure 10.4 presents the upper-body skin marker system and the name of the labeled markers.

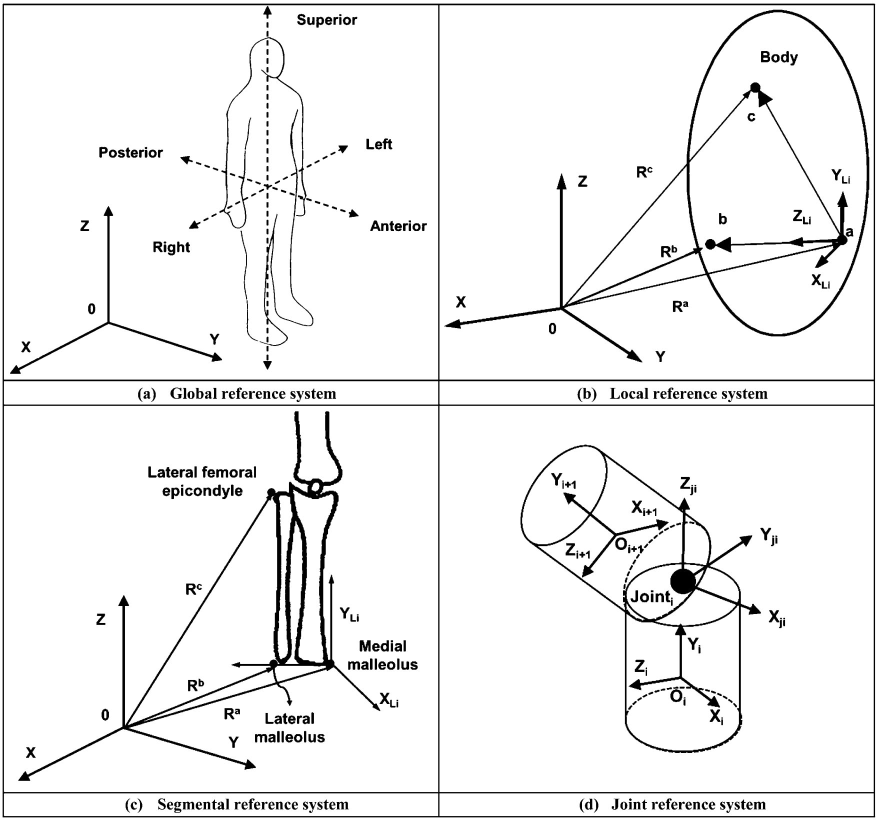

Fig. 10.5 Reference systems for movement analysis of human body

10.3.1.2 The Selection of a Reference System

In general, the reference system is defined as a system that uses coordinates to establish a position using three orthogonal vectors. Four reference systems are commonly used in the context of movement analysis (Fig. 10.5): the absolute reference system, local reference system (LRS), segmental reference system (SRS), and the joint reference system (Spoor et al. 1980; Cappozzo et al. 1996; Frigo et al. 1998; Mun et al. 2003). Each reference system has a different character and meaning. In particular, the LRS and SRS consist not only of three points in space but can also be used to analyze relative motion between segments. In addition, the SRS contains clear anatomical meanings such as proximal–distal, medial–lateral, and anterior–posterior. Therefore, the SRS is commonly used in biomechanics area, because it is relatively simple to understand (Rim et al. 2009).

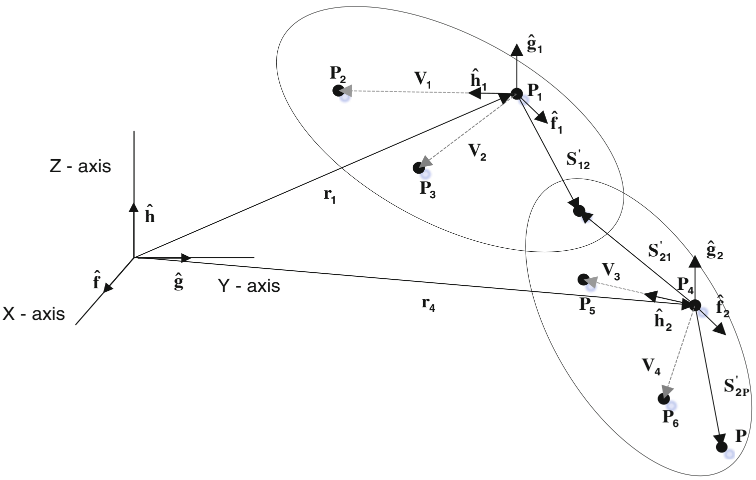

Fig. 10.6 Reference system configuration between two bodies

10.3.2 Actual Analysis Procedure: Joint Kinematic Analysis

In the field of motion analysis, the most frequently used method to calculate the angular orientation of body segments is the acquisition of the transformation matrix via evaluation of the angular displacement of a given body segment (Mun et al. 2003). The segment angular orientation is measured by the displacement of three non-collinear sensors on each segment (Fig. 10.6).

The sensor points on each of the body segments (denoted as points P1, P2 and P3 on the upper arm, and points P4, P5 and P6 on the lower arm) are then employed in the definition of the transformation matrixes, $A1$ and $A2$, which relate the body reference frames to the global frame (Rim et al. 2009). These transformations can be expressed as follows:

$$A_1 = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} \hat{f}_1 & \hat{g}_1 & \hat{h}_1 \end{bmatrix}, \tag{10.8}$$

where

$$\begin{aligned} v_1 &= P_2 - P_1 & \hat{h}_1 &= \tfrac{v_1}{\|v_1\|} \\ v_2 &= P_3 - P_1 & \hat{f}_1 &= \tfrac{x_1}{\|x_1\|} \\ x_1 &= v_1 \times v_2 & \hat{g}_1 &= \hat{h}_1 \times \hat{f}_1 \end{aligned} \tag{10.9}$$

and

$$A_2 = \begin{bmatrix} a'_{11} & a'_{12} & a'_{13} \\ a'_{21} & a'_{22} & a'_{23} \\ a'_{31} & a'_{32} & a'_{33} \end{bmatrix} = \begin{bmatrix} \hat{f}_2 & \hat{g}_2 & \hat{h}_2 \end{bmatrix}, \tag{10.10}$$

where

$$\begin{array}{ll} v_3 = P_5 - P_4 & \hat{h}_2 = \frac{v_3}{\|v_3\|} \\ v_4 = P_6 - P_4 & \hat{f}_2 = \frac{x_2}{\|x_2\|} \\ x_2 = v_3 \times v_4 & \hat{g}_2 = \hat{h}_2 \times \hat{f}_2 \end{array} \tag{10.11}$$

The transformation matrices can be expressed in terms of the Euler angles, as follows:

$$A_1 = \begin{bmatrix} c\phi_1 c\psi_1 - s\phi_1 c\theta_1 s\psi_1 & -c\phi_1 s\psi_1 - s\phi_1 c\theta_1 c\psi_1 & s\phi_1 s\theta_1 \\ s\phi_1 c\psi_1 - c\phi_1 c\theta_1 s\psi_1 & -s\phi_1 s\psi_1 - c\phi_1 c\theta_1 c\psi_1 & -c\phi_1 s\theta_1 \\ s\theta_1 c\psi_1 & s\theta_1 c\psi_1 & c\theta_1 \end{bmatrix} \tag{10.12}$$

$$A_2 = \begin{bmatrix} c\phi_2 c\psi_2 - s\phi_2 c\theta_2 s\psi_2 & -c\phi_2 s\psi_2 - s\phi_2 c\theta_2 c\psi_2 & s\phi_2 s\theta_2 \\ s\phi_2 c\psi_2 - c\phi_2 c\theta_2 s\psi_2 & -s\phi_2 s\psi_2 - c\phi_2 c\theta_2 c\psi_2 & -c\phi_2 s\theta_2 \\ s\theta_2 c\psi_2 & s\theta_2 c\psi_2 & c\theta_2 \end{bmatrix}, \tag{10.13}$$

where $c = \cos$ and $s = \sin$. Thus, the Euler angles for each segment can be determined via the following equations:

$$\cos\theta_1 = a_{33},\ \cos\theta_2 = a'_{33} \tag{10.14}$$

$$-\tan\phi_1 = \frac{\sin\phi_1}{-\cos\phi_1} = \frac{a_{13}}{a_{23}},\ -\tan\phi_2 = \frac{\sin\phi_2}{-\cos\phi_2} = \frac{a'_{13}}{a'_{23}} \tag{10.15}$$

$$\tan\psi_1 = \frac{\sin\psi_1}{\cos\psi_1} = \frac{a_{31}}{a_{32}},\ \tan\psi_2 = \frac{\sin\psi_2}{\cos\psi_2} = \frac{a'_{31}}{a'_{32}}. \tag{10.16}$$

10.3.3 Actual Analysis Procedure: Joint Kinetic Analysis

Joint forces and moments are calculated by external forces, kinematic information, and the subject's anthropometrical data, such as segmental mass, moment of inertia, center of mass, and length. In this procedure, Newton–Euler method is used to calculate the joint kinetic information (Spoor et al. 1980; Cappozzo et al. 1996).

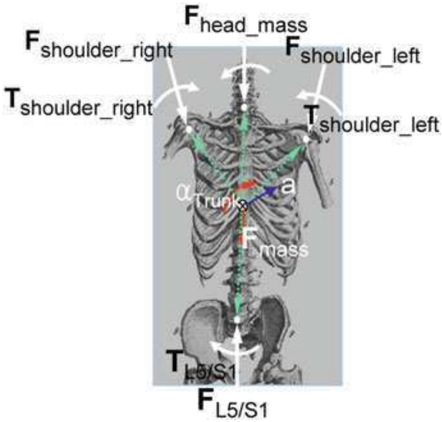

Fig. 10.7 Free body diagram of human upper body

This human upper-body linked system is broken up into isolated components, which are related to each other via interfacing forces and moments. Figure 10.7 presents the free body diagram of the trunk segment of the human upper body.

In the case of trunk segment, there are external forces from the shoulders, neck joints, and the joint between lumbar 5th (L5) and sacrum 1st (S1) segments. The kinetic information of the joint between lumbar 5th and sacrum 1st segments can be calculated using the trunk internal effect, such as the linear and angular acceleration of the trunk segment. The following equation is the Newton–Euler equation used to calculate the joint (L5/S1) forces and moments.

$$\begin{aligned} &\sum \bar{F} = m\bar{a} \\ &\bar{F}_{\mathrm{L5/S1}} + \bar{F}_{\mathrm{mass\_Trunk}} + \bar{F}_{\mathrm{C7/T1}} + \bar{F}_{\mathrm{L.shoulder}} + \bar{F}_{\mathrm{R.shoulder}} \\ &\quad = \mathrm{mass}_{\mathrm{Trunk}} \times \bar{a}_{\mathrm{Trunk.C.G}} \end{aligned} \tag{10.17}$$

$$\begin{aligned} &\sum \bar{M} = I\bar{\alpha} \\ &\bar{T}_{\mathrm{L.shoulder}} + \bar{T}_{\mathrm{R.shoulder}} + \bar{T}_{\mathrm{L5/S1}} + \bar{T}_{\mathrm{L5/S1}} + r_{\mathrm{R.shoulder}} \times \bar{F}_{\mathrm{R.shoulder}} \\ &+ r_{\mathrm{L.shoulder}} \times \bar{F}_{\mathrm{L.shoulder}} + r_{\mathrm{Head}} \times \bar{F}_{\mathrm{Head}} + r_{\mathrm{L5/S1}} \times \bar{F}_{\mathrm{L5/S1}} \\ &= \frac{d(I_{\mathrm{Trunk}}\bar{\omega}_{\mathrm{Trunk.C.G}})}{dt} \\ &= \left(\frac{d(I_{\mathrm{Trunk}})}{dt}\right)\bar{\omega}_{\mathrm{Trunk.C.G}} + I_{\mathrm{Trunk}}\bar{\alpha}_{\mathrm{Trunk.C.G}} \end{aligned} \tag{10.18}$$

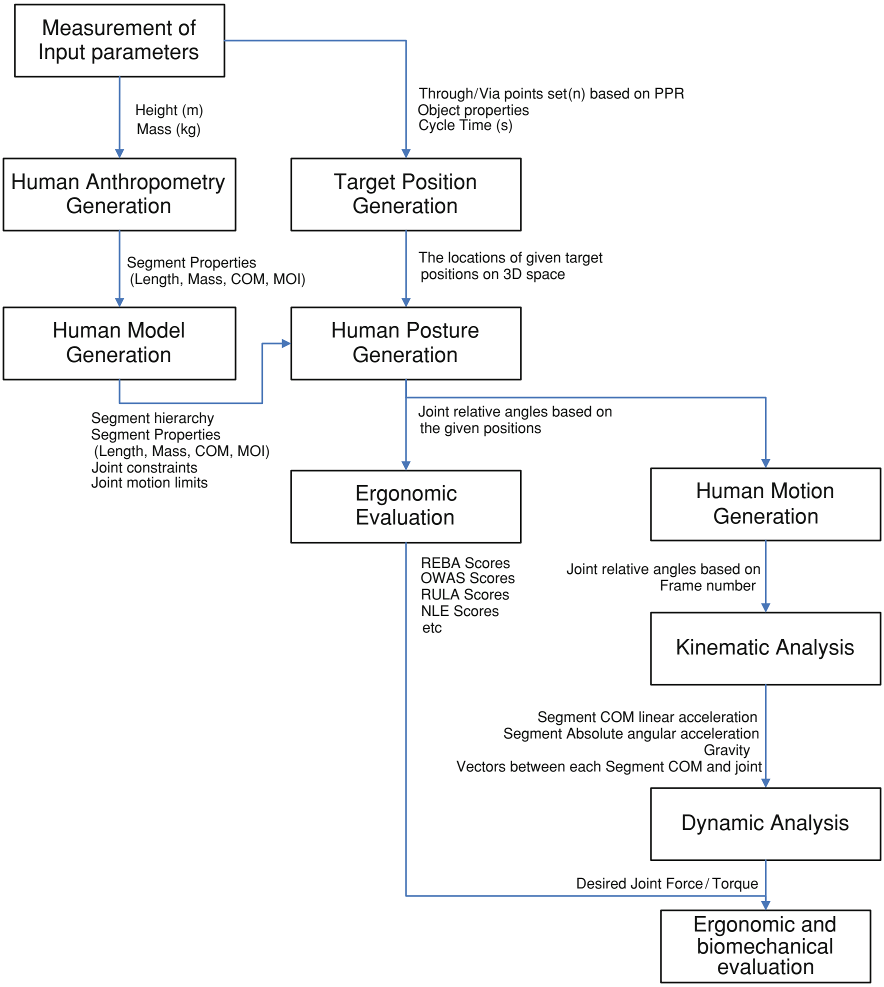

Fig. 10.8 Workflow of ergonomic and biomechanical analysis using a digital human model

10.4 Workstation Design and Ergonomics

10.4.1 Ergonomic and Biomechanical Analyses for Workstation Design

Figure 10.8 presents the workflow of the ergonomic and biomechanical analyses to design and evaluate a given working scenario in a virtual environment. The procedure used for workstation design and ergonomic evaluation consists of several activities. The human anthropometry generation and human model generation activities work on the construction of the digital human model, and the next three processes are to generate human postures in the given working environment (Rim et al. 2008; Kim et al. 2008). The last four processes are to analyze the kinematic and kinetic data generated by the working motions of the human. In this workflow, biomechanical analysis is carried out only when the results of ergonomic evaluation provide human jobs' changes are needed.

10.4.2 Case Study: Door Installation Process

For the evaluation of the proposed workflow and the developed human body–modeling methods, we applied these to a case study in automotive general assembly operations. In the first step, we defined the unit works and their work elements, material address, and storage method of general assembly shops. Using the data, we virtually constructed all objects, including products, racks, boxes, and so on. These were exported to the Digital Factory model. After the virtual factory construction, we generated the worker's postures using the optimization-based posture and motion prediction algorithm for each working posture, and then rapid upper-limb assessment (RULA) test was used to perform ergonomic analysis. Based on the RULA test, we performed biomechanical analysis using the inverse dynamic modeling method for the human jobs with high score on the relative loading scale of the RULA test.

RULA is a survey method to estimate postural loading of human body which is presented in McAtamney and Corlett (1993). It has a scoring system to be compared with action-level list as follow:

Action level 1: RULA score 1–2 means that the person is working in the best posture with no risk of injury from the work posture.

Action level 2: RULA score 3–4 means that the person is working in a posture that could present some risk of injury from the work posture, and this score most likely is the result of one part of the body being in a deviated and awkward position, so this should be investigated and corrected.

Action level 3: RULA score 5–6 means that the person is working in a poor posture with a risk of injury from the work posture, and the reasons for this need to be investigated and changed in the near future to prevent an injury.

Action level 4: RULA score 7–8 means that the person is working in the worst posture with an immediate risk of injury from the work posture, and the reasons for this need to be investigated and changed immediately to prevent an injury.

This case study was conducted by Rim et al. (2008). This subsection is cited to the case study. A list of human jobs for the "Door Install" process in a case study conducted for automotive general assembly. It consists of seven unit works. The detail of the "Door Install" process and the each unit work is as follow:

Remove (front/rear) door from hanger and then fit to the body: In the first operation, the unit works are divided into three parts, such as grip the door using a

Unit Work	Upper Arm	Lower Arm	Wrist	Wrist Twist	Total	Neck	Trunk	Total	Grand Score
1 	2	3	1	2	4	2	1	2	**3**
2 	2	3	2	1	5	1	1	1	**4**
3 	4	2	3	1	4	5	4	8	**6**
4 	3	2	3	2	4	4	2	5	**5**
5 	4	3	1	2	4	4	4	7	**6**
6 	3	2	1	2	4	4	4	7	**6**
7 	1	2	3	1	4	3	4	5	**5**

Fig. 10.9 RULA scores of the present jobs in "Rear Door Install" process of the case study

manipulator, remove the door from a door hanger, and fit the door to the car body.

Match (front/rear) door: This unit work is to match the door to the car body using a manipulator.

Check (front/rear) door and assembly with the car body: The last operation has three unit woks. In the each unit work, the worker checks holes on the door and the car body, assembles two bolts, and adjusts the torque using a torque wrench.

Figures 10.9 and 10.10 show the results of the RULA test for the "Real Door Install" process in the present and reformed working conditions, respectively. In the Figs. 10.9 and 10.10, each score presents the joint loading and total postural loading conditions. In the present working condition, the majority of the worker's exaggerative joint movements were in the human upper body (Rim et al. 2008). Especially, neck and lumbar joints were the most loaded parts among the upper-body joints in the third (fit the door to the body) and fourth unit works (match the door to the car body using a manipulator).

To reduce the exaggerative joint stress and improve the working condition, a new working environment and job scenario was proposed. Especially, the heights of the car body and the door were adjusted to reduce the exaggerative movement of neck and lumbar joints (Rim et al. 2008).

Unit Work	Upper Arm	Lower Arm	Wrist	Wrist Twist	Total	Neck	Trunk	Total	Grand Score
1 	2	3	2	1	4	2	1	2	**3**
2 	3	3	1	1	5	1	1	1	**4**
3 	4	3	2	1	4	5	5	8	**6**
4 	3	3	2	1	4	2	1	2	**3**
5 	3	3	1	2	4	3	1	3	**3**
6 	3	3	3	1	4	3	4	5	**5**
7 	3	2	1	1	3	3	4	5	**4**

Fig. 10.10 RULA scores of the reformed jobs in "Rear Door Install" process of the case study

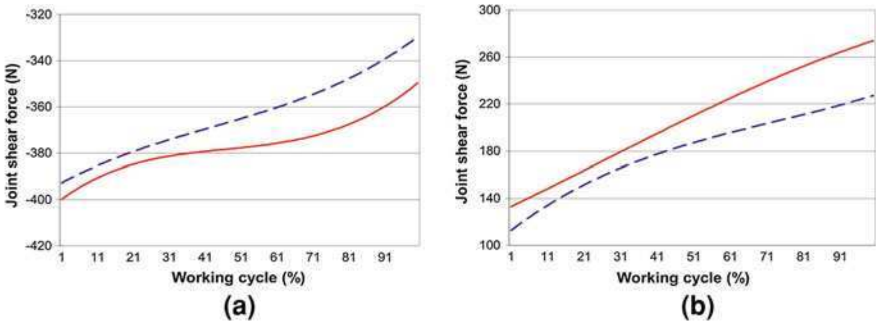

Fig. 10.11 Joint shear forces at L5/S1 joint during the third and fourth unit works of present and reformed working conditions (*bold line* present working condition, *dotted line* reformed working condition)

Figure 10.11 presents one of the kinetic analysis results, the shear forces at the joint between lumbar 5th and sacral 1st segments during the third and fourth unit works. In this case, the shear forces at the anterior/posterior and medial/lateral directions were reduced significantly in the reformed working condition.

The developed DHM tool using the introduced human body–modeling methods and the biomechanical analysis results for the reformed working condition are

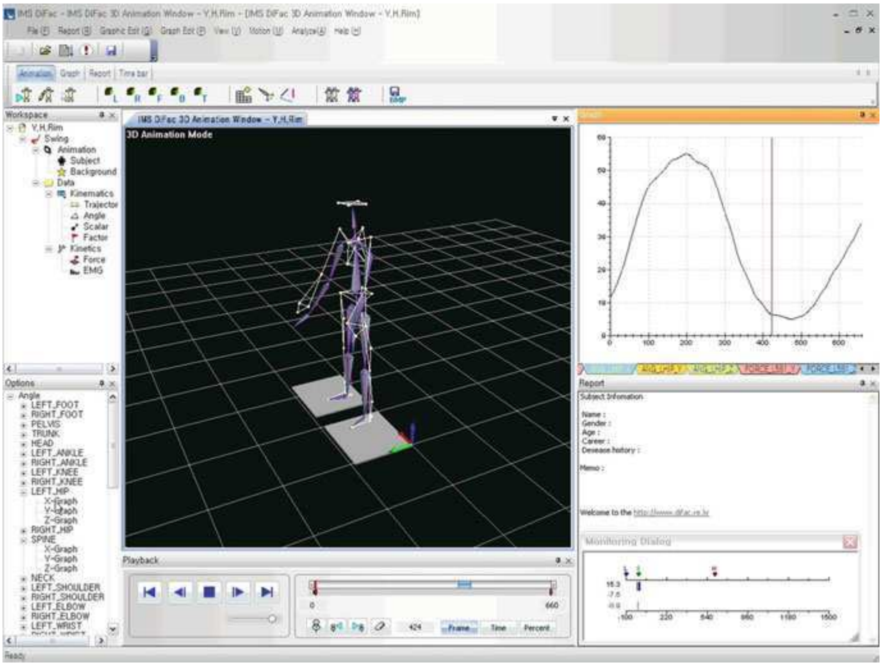

Fig. 10.12 Biomechanical analysis using the developed DHM tool

shown in Fig. 10.12. For this DHM simulation and the analysis, we used the inverse dynamic modeling method through experimental tests using a 3D motion capture system.

10.5 Conclusion

The DiFac project was designed for the development of the digital factory for human-oriented production systems to improve human safety in general factory scenarios. In this project, human body modeling is a key factor to apply DHM simulation methods to digital manufacturing tools to improve human safety. Therefore, a DHM tool has been developed to simulate given working scenarios and to improve human performance by testing human behavior at an early stage of the manufacturing development process. For the purposes, there were two technical challenges to automatically generate postures/motions of digital human models and to improve the accuracy of DHM simulation results**.** To achieve the two technical challenges, we introduced two different human body–modeling methods for DHM simulation, the developed DHM tool and the application to general automotive assembly tasks.

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Chapter 11
Flexible Integration of VR-Based Tools and Simulation Applications for the Planning and Optimization of Factories and Manufacturing Processes

Carmen Constantinescu

Abstract This chapter presents a new and innovative concept in the area of continuously integrated and collaborative factory planning. It presents the conceived and developed loosely coupled architecture in detail. The supporting virtual reality- and simulation-based tools are explained with a view to the planning workflow and the data change propagation. The implemented validation scenario gives a realistic representation of the planning workflow for factory layout optimization. It considers the static factory layout model and the dynamic material flow behaviour of the factory. The developed standardized data exchange format for the planning tools along the planning workflow is briefly described.

11.1 Problem Statement

The modern view on manufacturing engineering supports the incorporation of the life cycle paradigm into the factory as a whole, including its corresponding products, manufacturing processes and technologies. The idea of "Product Life Cycle" is essential for the path to sustainability as it expands the focus from the production site to the whole factory and product life cycle. The main idea behind the factory and product life cycle thinking is to reduce resource usage and improve the technical and social performance, during the various stages of a factory's and product's life (Constantinescu et al. 2005; Wrisberg et al. 2002). In this context, Life Cycle Management is the application of life cycle thinking with the aim to manage the entire life cycle of the factory and its products, manufacturing processes and services towards more sustainable consumption and production.

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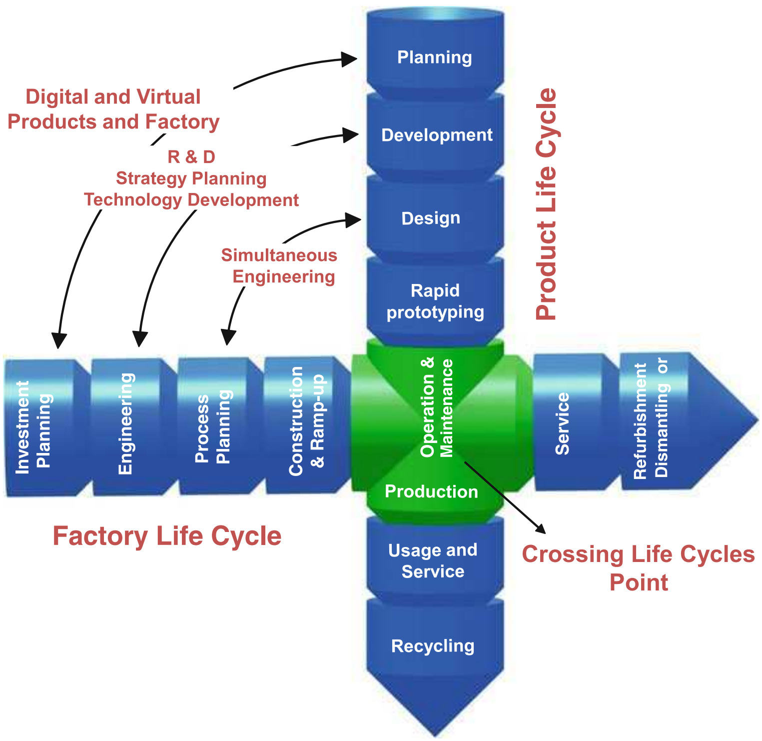

Fig. 11.1 The harmonisation of Product and Factory Life Cycles under the "Crossing-Life Cycles Point"

This approach is based on the image of a 3D life cycle space for factories, products and manufacturing processes (Fig. 11.1). Each of these entities has its own life cycle, consisting of specific phases.

Each factory follows a life cycle from its initial conception in the mind of an entrepreneur to the ecological dismantling, through a series of stages or phases.

Figure 11.1 traces the factory's life along investment planning, engineering, process planning, construction and ramp-up, production, service and maintenance and finally, dismantling or refurbishment. Two states of a factory and its manufacturing processes have been distinguished: "digital" and "virtual", making a clear distinction between the used models, methods, technologies and tools of advanced manufacturing engineering (Aldinger et al. 2006). The Digital Factory represents the static image of a factory, modelled and represented by using digital manufacturing and modelling technologies. The projection of the factory into the future, through simulation and 3D/virtual and mixed reality technologies, represents the Virtual Factory.

Figure 11.2 presents the difference between the digital and virtual factory.

In the authors' view of a digital and virtual factory, the factory life phases can be structured as follows: From investment planning to construction and ramp-up,

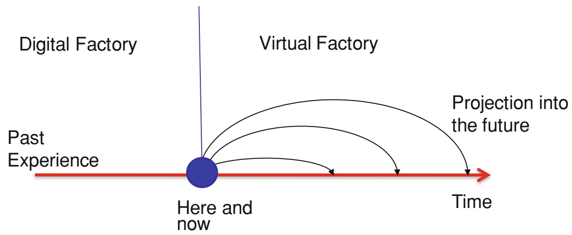

Fig. 11.2 Difference between the digital and virtual factory

the factory is digital. In these phases, it exists in both digital and virtual form, being permanently optimized through simulation. Then, the factory is constructed and ramped up. All remaining phases trace the real factory.

Simultaneously, the products, which will be manufactured in the factory, are passing through the main phases of their life cycle: planning, development, design, rapid prototyping, production, usage and service and recycling. By transferring the authors' concepts concerning the digital and virtual factory to the products, the products are digital and virtual between the planning and the rapid prototyping phases. The real product lives from production to recycling.

The central part of Fig. 11.1, the overlapping of the factory's operation and maintenance and the manufacturing of products in the so-called production phase represents the crucial and, at the same time, critical point called "Crossing-Life Cycles Point." Here, the *virtual products* and *factories* become reality. The real product is being manufactured in the real factory. The manufacturing processes are being implemented by using the most suitable technologies. At this point, all the already performed engineering activities and efforts have to be proved and verified. During this phase, the real factory has to be highly transformable to quickly respond to the changes occurring in the product world: frequent product launches, increased product complexity as a consequence of using advanced and emerging technologies (e.g., the fast development of micro- and nano-electronics), increased micro computerisation and the development of new materials.

The crossing-life cycles point shows the results of the preceding phases concerning the manufacturing of products under optimal conditions (time, quality, costs, etc.). The point does not only highlight the efficiency and effectiveness of the used models, methods, technologies and tools for planning and designing products, processes and factories in the digital and virtual world but also the appropriateness of using them. The main advantage resulting from this approach is the transformability and changeability of the factory's structures throughout their whole life, according to the manufactured products, the corresponding manufacturing processes and the technologies used under economical conditions. Thus, in the operation phase, the factory is already prepared to react to changes regarding a new release of a traditional product or a new product, a newly implemented state-of-the-art manufacturing process or the use of an innovative technology. These foreseen and possible changes have already been taken into consideration in the planning phase. Then, the factory is able to adequately respond and to adapt itself to these changes and turbulences to remain competitive. The information gathered in the production phase represents a valuable input for continuous replanning and adaptation of the factory.

11.2 Unified and Sustainable Life Cycle Challenges and Risks

An orchestration or harmonisation of the specific life cycle phases of products, manufacturing processes and technologies with the planning phase of the factory represents a great challenge. This approach is called *Unified and Sustainable Life Cycle Management* (Westkämper et al. 2006). All the subordinated factory entities, the manufactured products, the corresponding manufacturing processes and the used technologies, have their own life cycles. In the end, each life cycle can be represented as an independent software application; therefore, a software technology infrastructure has to be developed to enable the seamless linkage and integration of software applications and systems, representing various life cycle aspects. As phases of these life cycles tend to be independent of each other, the current challenges and then the research efforts have to be coordinated towards an integrated and unified life cycle paradigm. This unified life cycle paradigm builds on current technologies and is backwards compatible, taking into account future emerging technologies. Only if two of these life cycles coincide and one affects the other, connectivity and a transfer of information at the interface can be established. The current research approaches have to identify: (1) linkage points (i.e., portals) between life cycles, (2) the type and form of data passing between life cycles (i.e., supported by a common data base) and (3) conditions for the interaction and communication of life cycles (i.e., with the help of a workflow manager). This is expected to be overcome by developing and integrating new technologies and tools (e.g., information and communication technologies), digital manufacturing technologies, collaboration models and tools used to trace factories, products, processes and technologies during their life cycles, from engineering to the end of their lives. Several strategies for supporting the required orchestration have to be mentioned: applying simultaneous engineering for bridging the product design and process planning, and the development of suitable strategies for Research and Technological Development to link product planning, development, factory investment and engineering. The last one can be achieved through the development of advanced and innovative manufacturing technologies and methodologies.

The envisioned solution for minimising all the risks and losses related to the crossing-life cycles point is the development of an environment for factory life cycle management by collaboratively integrating the latest technologies and tools, which are used to follow the factories and their products along their life cycles. The vision of this work represents the "transformable and adaptable factory", which has to quickly and appropriately react to the internal and external turbulences by using new collaboration and integration models, methods and procedures along the value chain.

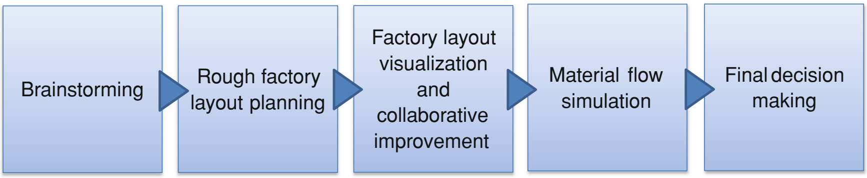

Fig. 11.3 Factory Constructor workflow

11.3 Continuously Integrated Planning and Optimization of Factories and Manufacturing Processes

It is intended to bring the approach of a sustainable life cycle management presented above into reality by developing and implementing a digital manufacturing environment, which continuously integrates virtual reality (VR)-based systems and simulation tools for the purpose of factory and process planning and optimization.

Despite the identified and recognized phases, design and planning, construction, operation and maintenance, refurbishment or obsolesce and end-of-life phase or dismantling, this work—the Factory Constructor—focuses on the first phase, namely, the design and planning of the factory. In this phase, the factory processes and its production facilities are being planned.

11.4 Factory Constructor: DiFac Solution for Flexible Integration of VR and Simulation Tools

Functional architecture was developed as a basis for the implementation of the digital activity Factory Constructor. Figure 11.3 illustrates the corresponding Factory Constructor workflow.

The Factory Constructor contains five different digital tools: the Web-based brainstorming and decision-making tool iGDSS—Intelligent Decision Making; the VR-based Planning Table for participative, interdisciplinary and intuitive factory layout planning (Sect. 11.5.1); the distributed VR environment GIOVE Virtual Factory for collaborative factory layout visualisation and improvement (Sect. 11.5.2); the Web-based eM-Plant Simulation Tool for material flow simulation (Sect. 11.5.3); and the collaborative Web platform iPortal for content management.

According to the Factory Constructor workflow, the following steps have to be processed using the above-mentioned digital tools:

- Generation of a large number of ideas, involving several people with different roles, using the iGDSS tool to get a first vision of the future factory configuration.

- Planning of the rough layout using the Planning Table in a participative meeting, having managers, planners and workers with different interdisciplinary fields as participants. The intuitive VR user interface of the Planning Table simplifies the planning process for the users.
- Visualisation and improvement of the factory layout using the GIOVE Virtual Factory tool. With this tool, the planners located at different sites can work collaboratively in a distributed realistic virtual environment.
- Analysis of the new layout with the eM-Plant Simulation Tool and identification of bottlenecks and potentials for optimizations.
- Visualisation of the results in the GIOVE Virtual Factory. The planners can collaboratively optimize the factory depending on the visualised final layout.
- Taking of a final decision on alternative layout configurations with the iGDSS tool.

The digital tools are divided into the VR/simulation-based factory-planning tools and the group collaboration tools for brainstorming and decision-making. Based on the described methodology, no exchange of factory data is required between the VR/simulation-based factory-planning tools and the group collaboration tools. The Factory Constructor provides the following two alternative architectures for the data exchange between the above-mentioned VR/simulation-based factory-planning tools:

1. *Hub-based integration*: This complex software architecture is based on a central data management hub (Factory Constructor Hub), which manages and exchanges all the data of the different Factory Constructor applications (Dürr et al. 2008) similar to the approach of Bracht and Masurat (2005).
2. *XML-based integration*: During the development phase, the DiFac consortium figured out that a much more flexible architecture was required, which is also suitable for SMEs. Therefore, a generic architecture was developed in which the Factory Constructor components exchange the factory-planning data through an XML file format (described in Sect. 11.6) by creating a loosely coupled integration architecture. All advantages of a flexible integration are presented by Schuh et al. (2008).

Figure 11.4 illustrates the XML-based data exchange between the Factory Constructor components. The following steps describe the data exchange in the Factory Constructor workflow:

1. Upload the XML-based factory layout (position and rotation of factory objects), created by the Planning Table, to the iPortal.
2. Download the XML-based layout to the GIOVE Virtual Factory. Improve the layout (change positions, rotations or add/delete new objects).
3. Upload the improved layout file to the iPortal.
4. Download the layout to the eM-Plant Simulation Tool. Generate a simulation model and run the simulation.
5. Upload the simulation results as an XML file to the iPortal.
6. Download the simulation results and visualise them in the GIOVE Virtual Factory.

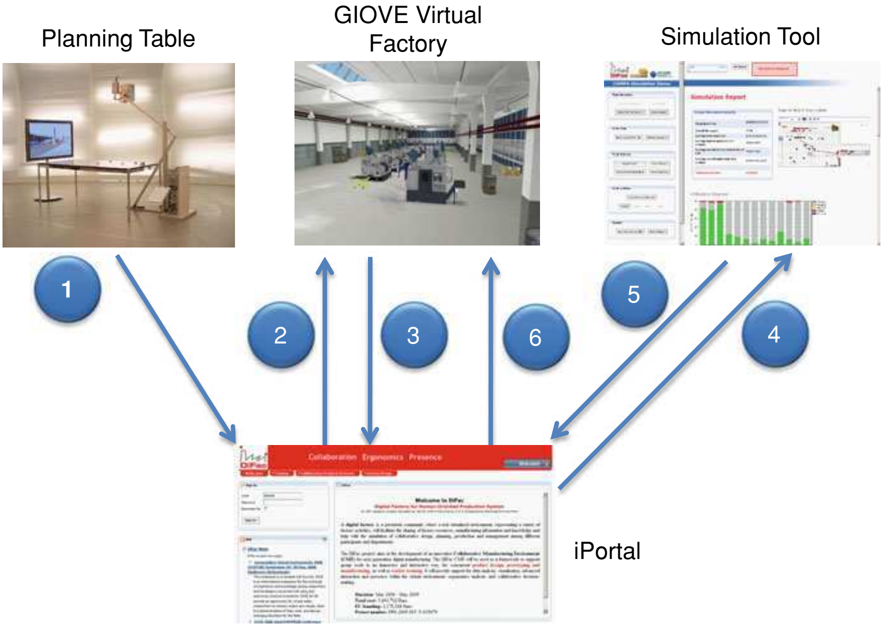

Fig. 11.4 Loosely Coupled Factory Constructor architecture

Steps 2–6 can be iterated until the final layout is approved.

In this architecture, the central data exchange component is the Web collaboration platform iPortal. The planners exchange factory data between the Factory Constructor applications through the document repository of the iPortal. The following chapters describe in detail the integrated digital factory-planning tools, depending on the Factory Constructor workflow and the loosely coupled architecture.

11.5 Factory Constructor Validation Scenario

This subchapter describes the Factory Constructor workflow validation scenario with the corresponding digital tools, also concerning the data exchange between the planning tools.

11.5.1 Rough Factory Layout Planning

Based on a first collaborative brainstorming, the Planning Table (Fig. 11.5) is used to conceive the first rough factory layout in a participative planning session, supported by a factory-planning consulting company.

Fig. 11.5 Planning table

The Planning Table (i-plant Website http://www.i-plant.de/) is an efficient tool designed to facilitate team-based planning processes. It is a tool that supports the generation of 2D- and 3D-models and charts of factory-planning projects. The Planning Table has been successfully applied in mechanical engineering, automotive engineering, office planning, in the textile industry and in many other industrial sectors. The main field of application for the Planning Table is factory planning—a highly complex task that can only be fulfilled by proceeding on an interdisciplinary team-orientated basis. Therefore, it is designed to be extremely easy to handle. The planning area is projected on the surface of a normal table. The Planning Table's innovative form of interaction is based on a video-processing system that introduces a novel user interface through advanced image recognition and presentation techniques. Using small reflecting bricks, several users can insert, select and shift different objects at the same time within the planning area on the table. This allows a dynamic and continuous modification of the planning area. A second and parallel projection surface gives a 3D view of the planning area. This view is controlled by a fictitious camera at 2D level. It enables views from various angles and circuits through the entire planning area. To ensure high-planning quality, problems should not be considered by single experts, but need to be jointly discussed and assessed by the project team. The Planning Table allows the synchronised participation of experts from all involved disciplines, e.g., architecture, logistics or any other field. It enables the team to move forwards in the planning processes, still taking the different views into consideration that the disciplines hold simultaneously. Hence, staff from all organisational levels of the company can participate in the planning process without intensive and costly training. The Planning Table is equipped with an extensive library of virtual modules, such as machines, logistic components and further elements, designed to meet the specific needs of each customer. It has been shown that integrating the Planning Table into industrial planning processes is a long-term benefit in many respects:

Fig. 11.6 GIOVE virtual factory

- The easy handling encourages all involved parties to actively participate in the planning process and to consequently identify with the outcome,
- The 3D visualisation is a useful tool for collaboratively demonstrating, discussing and evaluating the results.

Combining the team-based intuitive planning process with a 3D result display creates a communication platform that allows all parties involved in the planning process to communicate effectively and to avoid misunderstandings—even if the terminology differs. Because of the optimization of the communication flow between all participants in the planning processes, the planning time can be reduced and the quality of planning processes can be improved.

The Planning Table provides numerous ways to display the planning results and to exchange these results with other tools by exporting data. In the Factory Constructor workflow, the exported XML-based rough factory layout file is uploaded to the iPortal content management system and can be accessed for the subsequent planning processes.

11.5.2 Factory Layout Visualisation and Collaborative Improvement

For detailed optimizations of the layout, the planners situated at different locations can download the current factory layout from the iPortal and use the GIOVE Virtual Factory environment to improve it incrementally in distributed planning sessions.

The GIOVE Virtual Factory is a collaborative virtual environment where a factory layout can be designed and explored (Fig. 11.6).

An optimized rendering process allows achieving full textured high-quality graphics, enhancing the sense of presence when exploring the virtual factory. This allows a more complete feedback and can be well understood by unqualified

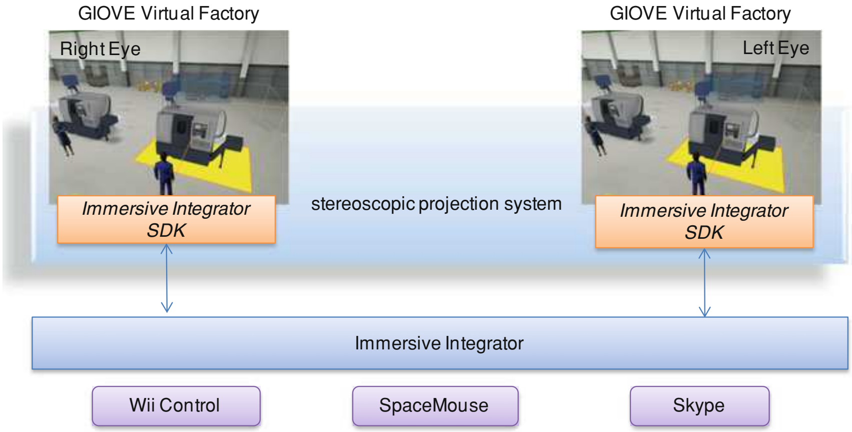

Fig. 11.7 GIOVE virtual factory and immersive integrator

employees like blue collars: They can enter the collaborative virtual environment and easily provide their opinion about ergonomics issues. The GIOVE Virtual Factory provides full capability to import and export factory layouts as, for example, Factory Constructor XML files.

The improved version of the factory layout is uploaded to the iPortal content management system by the planners, where it is accessible for further optimizations.

To increase the ergonomics aspects using the GIOVE Virtual Factory distributed environment, it was connected to the DiFac pillar component immersive integrator. The immersive integrator is a device integration middleware that is conceived to enhance the user interaction in collaborative virtual manufacturing planning environments. This middleware allows the users to participate in the collaborative and distributed factory layout planning process using different very intuitive and realistic 3D input and output devices as well as enhanced communication technologies. The immersive integrator enables the user of the GIOVE Virtual Factory to switch between different input devices, e.g., SpaceMouse, Nintendo Wii controls or tracking systems, directly in the control menu. The fundamental architecture is presented in Fig. 11.7.

It is possible to visualise the distributed environment on a standard desktop PC. The visualisation can be switched to stereoscopic projections as well. Therefore, the immersive integrator enables the remote communication between two visualisation components that run on two different PCs, one for the right and one for the left eye. To support the collaboration between the participants in the distributed environment, the Skype API is connected to the GIOVE Virtual Factory through the immersive integrator. A VoIP session between all participants is established, when a distributed factory-planning session is started.

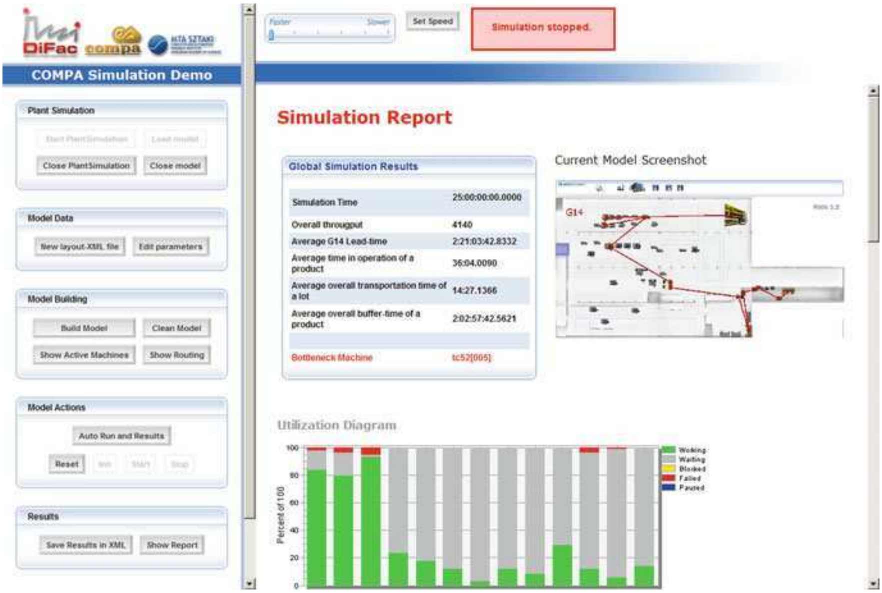

Fig. 11.8 Simulation tool

11.5.3 Material Flow Simulation

To support the planning process, the dynamic behaviour of the factory layout is analysed using a material flow simulation. The main objective of this simulation is to evaluate the manufacturing processes in the designed layout and to locate the weak points of it with special respect to the flow of material and the throughput of the overall system. The results provided by the simulation module of the Factory Constructor are analysed in a collaborative way and thus they will support the decision on the new design. The simulation model is built based on the current factory layout accessible on the iPortal (Fig. 11.8).

The aggregated results of the simulation runs are presented in a Web-based application and are used in the collaborative decision-making process. These results can be exported as Factory Constructor XML files, uploaded to the iPortal and loaded to the GIOVE Virtual Factory for evaluation processes.

11.6 XML-Based Integration of Digital Tools

The fundamental requirement for continuously integrated digital planning and optimization of factory and manufacturing processes is a standardized data exchange format. In the scope of the digital activity Factory Constructor, a prototypical standardised exchange format for the factory layout data has been

```
<?xml version="1.0" encoding="utf-8"?>
<Layout Name="COMPA_layout_modified"
FactoryDefinition="COMPA_factory_definition.xml"
Version="1">
  <Building Name="compa" Type="compa">
    <Position X="10429.5" Y="476.919" Z="-3814.37" />
    <Rotation X="0" Y="0" Z="0" />
  </Building>
  <Machine Name="m3[001]" Type="m3">
    <Position X="14296.3" Y="103.091" Z="-2644.29" />
    <Rotation X="0" Y="0" Z="0" />
    <Product>G14</Product>
  </Machine>
  <Machine Name="wmgrande[001]" Type="wmgrande">
    <Position X="12973.8" Y="160.069" Z="-698.631" />
    <Rotation X="0" Y="-90" Z="0" />
    <Product>G14</Product>
  </Machine>
  <Transport Name="trolley[006]" Type="trolley">
    <Position X="10263.8" Y="48.4838" Z="-5289.1" />
    <Rotation X="0" Y="-135" Z="0" />
  </Transport>
  <Worker Name="FemaleWorker[003]"
Type="FemaleWorker">
    <Position X="8094.44" Y="162.609" Z="-5848.01" />
    <Rotation X="0" Y="-150" Z="0" />
    <Product>G14</Product>
    <MachineUsed>tc66mc[006]</MachineUsed>
  </Worker>
  …
</Layout>
```

Fig. 11.9 Factory Constructor XML example

Table 11.1 Factory Constructor XML schema nodes

Node type	Description
<Building>:	This node saves the name, position and rotation of the factory building.
<Machine>:	The name, the type of machine, the position and the rotation of a machine can be saved in this node type.
<Transport>:	Transport objects, such as e.g., trolleys, can be defined using the transport node.
<Worker>:	Additional workers can be placed in the layout. These human resources can be saved in the <Worker> tag with the name, the type of worker, the position and rotation.
<Product>:	For a machine or a worker, it is possible to define which product will be manufactured by the resource with the <Product> tag.
<MachineUsed>:	For workers, it is required to define at which machine they are working.

developed and validated in the Factory Constructor scenario. Based on Kühn (2006), the common XML (Extensible Markup Language) can be applied as factory wide data exchange format (Fig. 11.9).

Table 11.1 lists the nodes that can be used to configure the layout of a factory in an XML structure.

An enhanced data exchange format for the integration of digital factory planning tools is AutomationML (Draht (2010). The participants of the AutomationML organisation are several key players in the area of digital factory, e.g., Siemens PLM Software.

11.7 Conclusion

This paper presents a step towards the integration of digital manufacturing technologies and of the corresponding tools for the modelling, simulation, optimization and visualisation of factories in the digital activity Factory Constructor of the DiFac project. The methodology for the Factory Constructor is conceived based on the Factory Life Cycle philosophy presented by Westkämper et al. (2006).

The continuously integrated Factory Constructor can support the factory layout planning decisions in both perspectives: The 3D static layout planning and evaluation as well as the dynamic analysis using simulation technologies. No special tool is required to carryout a factory layout design project in the DiFac Factory Constructor. The only and very important prerequisite of such a project is the off-line analysis of the planned layout and the preparation of the Planning Table of the GIOVE Virtual Factory and the simulation tools.

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Chapter 12
GIOVE Virtual Factory: A New Viewer for a More Immersive Role of the User During Factory Design

G. P. Viganò, L. Greci, S. Mottura and M. Sacco

Abstract The need to solve a wide range of complex tasks urged companies to adopt new software tools, including Virtual Reality (VR) and Augmented Reality (AR), in their production chains. Major software houses released a lot of tools to help experts to manage different complex tasks, included the design or the modification of the layout of a production plant. Unfortunately, such tools are far from being integrated in a unique tool. Furthermore, the small-to-medium enterprises prefer a more customized and less expensive solution (Consoni et al. J Intell Manuf 17(6):725–735, 2006). In this context, GIOVE virtual factory (GIOVE VF), a tool for the collaborative design and review of a factory layout, was developed by ITIA-CNR (Istituto di Tecnologie Industriali e Automazione, Consiglio Nazionale delle Ricerche, Italy) and integrated with the other DiFac components of the Factory Constructor (Sacco et al. Human computer interaction conference, Beijing (PRC), 25–27 July 2007; Mottura et al. 57th CIRP general assembly, Dresden, Germany, 19–25 August 2007; Smparounis et al. 14th international conference on concurrent enterprising, Lisbon, Portugal, 23–25 June 2008; Dürr et al. 14th international conference on concurrent enterprising, Lisbon, Portugal, 23–25 June 2008; Constantinescu et al. 14th international conference on concurrent enterprising, Lisbon, Portugal, 23–25 June 2008).

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12.1 Introduction

GIOVE VF has been developed onto GIOVE (Graphics and Interaction for OpenGL-based Virtual Environments), a set of libraries and tools designed for the creation of collaborative virtual environments. GIOVE allows the realization of real-time 3D interactive scenes including working digital representations of objects, products, systems that are being designed and evaluated. This kind of virtual environments can also be shared among different users, connected from different locations and collaborating to the same project.

12.2 GIOVE

GIOVE development started few years ago and the earlier versions were successfully applied in other research/industrial projects related to virtual prototyping (Viganò et al. 2007) and product customization (Mottura et al. 2007). ITIA previously worked on this topic in other projects, such as ManuFuturing (Sacco et al. 2000; Boër et al. 2000), MPA (Modular Plant Architecture), (Viganò et al. 2002; Mancini et al. 2004), and EUROShoE (Sacco et al. 2004) using different commercial development tools. Within DiFac project, GIOVE was finally mature to be applied also to the factory layout design.

12.2.1 GIOVE Architecture

For some years, developers at ITIA worked with commercial solutions to build Virtual Environments (i.e., Vega, by Paradigm Simulation Inc.), but ITIA dismissed commercial products for problems related to their cost (also burdening the end user), to their limited extensibility and to the possibility to get the chosen product discontinued. The goal was to reduce development time and resources reusing software modules, having a complete, modular, and easily extensible framework available.

Therefore, ITIA developers evaluated freeware libraries and found mostly fragmented solutions, often hard to be integrated each other and extended with new features. Their intent was to build something that will be able to follow the evolution of hardware and software technology and to adapt to diverse applications. They were interested in defining standard exchange formats and software template modules that can be reused in each application. These considerations suggested to develop a new complete framework for virtual environments development: GIOVE.

Software modules grouped in libraries compose GIOVE. The basic library (GIOVE Library) aims to support the lower-level development and a higher-level library (GIOVE Toolkit) to build the GIOVE VF and the other GIOVE tools.

The following Unified Modeling Language (UML) diagram (Fig. 12.1) shows the structure of these modules and their relations.

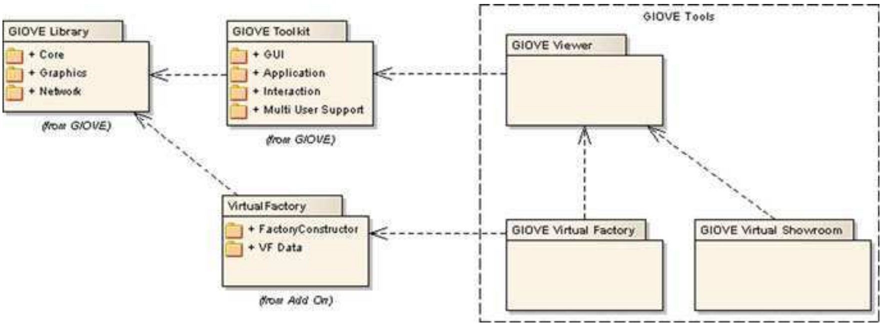

Fig. 12.1 GIOVE tools, the various modules and their relations

GIOVE Library includes three main modules:

- *A core library*: The basic component needed by all the other modules for the creation of the environment.
- *A graphics module*: Basic image-processing, filters to import/export images and 3D models (Autodesk 3ds and Wavefront OBJ), a scene graph-based rendering engine (using OpenGL 1.5).
- *A network module*: Basic session-level support for networking.

GIOVE Toolkit depends on GIOVE Library and provides a higher-level programing interface for the rapid development of GIOVE Tools. The development of GIOVE Toolkit during DiFac project was directly driven by the development of GIOVE Tools; thus, it includes all the common functionalities exploited by the tools, grouped into the following main components:

- *Graphical user interface (GUI)*: An OpenGL-based facility that makes interface widgets available for an immersive virtual environment (see next paragraph).
- *Application*: Most of the features needed to setup and run an AR and VR application.
- *Interaction*: Input devices management, navigation, direct manipulation facility.
- *Multiuser support*: A networking protocol implemented on the GIOVE network module to allow a virtual environment to be shared among one or more users connected over the network.

The rendering engine of GIOVE is mainly based on OpenGL 1.5, even if it is scalable with older versions (starting from 1.1). The choice to not use OpenGL 2 was driven by the need to have the maximum scalability over the existing hardware, even exploiting the new graphics features via the OpenGL ARB (Architecture Review Board) extensions. Regarding the 3D models, the need was to have a realistic appearance for virtual objects, to exchange data via a common format with other tools, and to achieve this result rapidly without spending money for commercial SDK (Software Development Kit). This led to add to GIOVE the support for Autodesk 3ds and Wavefront OBJ as 3D file formats. In the conclusions of this chapter, further developments (for both the rendering engine and the 3D format support) will be outlined.

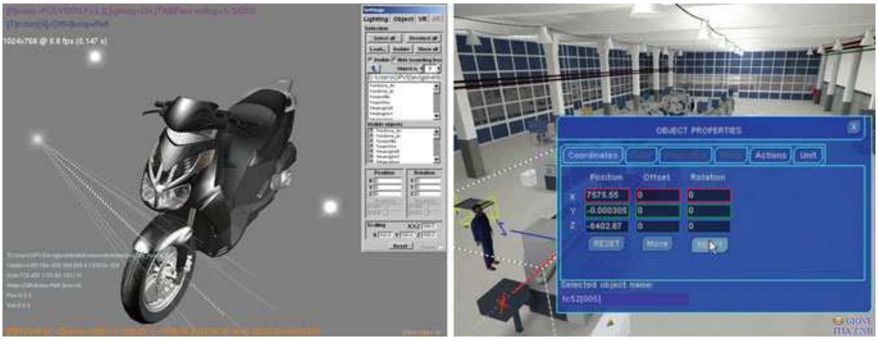

Fig. 12.2 A classic Windows GUI (*left*) and the GIOVE VF GUI (*right*)

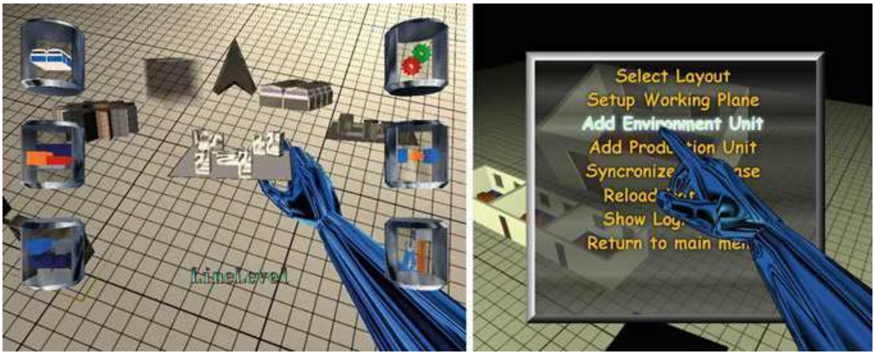

Fig. 12.3 Two possible immersive VR GUIs, the first one was developed within the MPA project (Viganò et al. 2002)

12.2.2 GIOVE GUI

GIOVE VF is designed to run both in a window or in full screen mode, and even on a set of screens composing an immersive projection system. For this reason, instead of creating a traditional GUI based on Windows menus and buttons, the GUI component was designed to be displayed in the same rendering context of the virtual environment, allowing the use within immersive VR systems.

The first prototype was built starting from a free open-source library (OpenGLUI, http://sourceforge.net/projects/openglui). A new version of GIOVE VF is planned, with a more complete and flexible GUI module, and a tool will be developed to visually build up any kind of needed interface (GIOVE GUI Editor).

This new approach aims at getting a common basic application-programming interface (API) for the creation of any type of interface, ranging from a traditional Windows-like interface (see Fig. 12.2) to immersive VR GUIs. The Fig. 12.3 shows the concept of possible immersive VR GUI implementations.

When interacting in an immersive Virtual Environment, a user can wear special devices, such as data gloves, that allow a more natural but less accurate interaction (e.g., with the mouse pointer, you can select small buttons; with your virtual finger, you need something more suitable, specially if you have not a tactile feedback).

Note that it is possible to implement a classic GUI rendered in the same context as the virtual environment, but it is not possible to implement an immersive 3D GUI using the classic controls (Windows menus, buttons, etc.) provided by the operating system API (e.g., Win32 API).

12.2.3 GIOVE Tools

All the tools developed with GIOVE share the large functionalities subset provided by GIOVE Toolkit.

GIOVE Viewer was developed as a general-purpose tool, implementing all the GIOVE Toolkit basic functionalities, used as a testing application and for the VE authoring. Two other tools were derived from it:

- *GIOVE Virtual Showroom* (Smparounis et al. 2008): Very similar to GIOVE Viewer, it is oriented to the configuration and the evaluation of a virtual prototype. It was applied in DiFac project both to carpets and to laser-cutting machines, further information in the "Case studies" paragraph.
- *GIOVE VF*: It provides the factory layout design facility, thanks to an "add-on" module (the Virtual Factory module in the UML diagram), which provides serializable data structures to manage the entities that represent machines, transport systems, workers, and so on.

GIOVE VF and GIOVE Virtual Showroom use two different scene formats: While the first one is based on the layout definition, the second one is more oriented to the virtual-world content. Furthermore, in GIOVE VF, user's actions are restricted to the modification of the layout; thus, the full control on the VE is not allowed in this case.

GIOVE VF allows designing a layout, to add information about the process and to share data with other tools, thanks to XML documents with a defined XML schema. These data are included into a project structure together with 3D models, textures, and other information.

The tool can run in different modes depending on the project phase and the collaboration mode required: single user or collaborative session.

When a single user is working, two different modes are available:

- *Authoring mode*: creation of the Virtual Environment and preparation for the final use
- *Standalone mode*: interaction with the Virtual Environment according to the rules defined in the authoring phase

Fig. 12.4 Client (*left*) and server (*right*) GUI in the GIOVE VF session setup panel. Note the "Skype conference" button on the server side

When a collaborative session is requested (various users share the same virtual environment), the users interact in the Standalone mode, but they can see each other and their activity. In this case, they can run GIOVE VF in two possible ways:

- *Server mode*: A user accepts connections from other clients and starts a collaborative session. There can obviously be only one server per session.
- *Client mode*: The users connect to the same server and they wait for the session to be started.

12.2.4 Skype API Integration

When the Virtual Factory is running in collaborative mode, several users can share the same virtual environment to review the factory layout. The integration of a voice conference system also allows the participants to discuss about possible changes or describe the modifications they have just made, instead of explaining what they are doing using the embedded chat system while interacting with the Virtual Environment. Even if it is possible to run a voice conferencing program (such as Skype™) in background, it should be uncomfortable to access the program GUI for the conference setup and management, in particular when the Virtual Factory is running in full-screen mode, eventually on a large-screen watched by more users. This is the reason why GIOVE VF implements a link to Skype™ API, controlling Skype™ directly from the Virtual Factory GUI (Skype™ was chosen also for this reason, not only for its popularity; see Fig. 12.4).

In this way, the server can automatically call all the clients connected just pressing a button, and when a client disconnects, he or she is automatically disconnected from the Skype™ conference as well. The Skype™ GUI can be set in

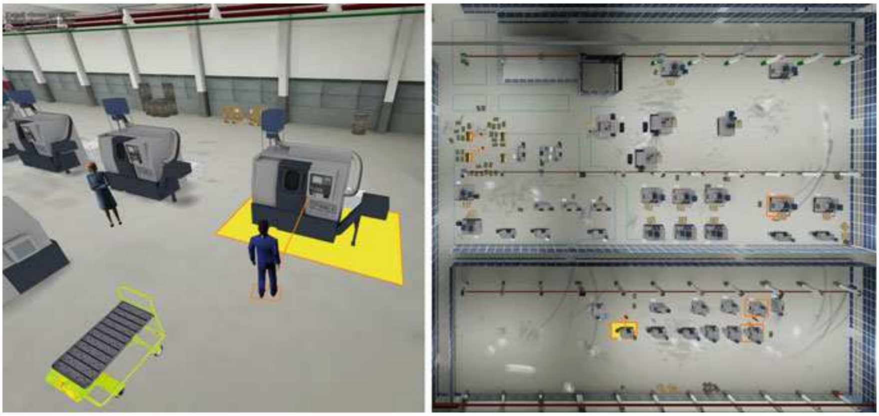

Fig. 12.5 Two different views on the factory layout: walking inside the virtual factory (*left*) and the *top view* (*right*) with the roof automatically hidden

silent mode while a voice conference is active in GIOVE VF, so any pop-up message is disabled (this can be useful in full-screen mode).

Furthermore, while users can see each other in the Virtual Factory, they can see other avatars flashing while talking.

12.2.5 Factory Layout Design

The designed factory can be explored walking around and checking the layout in the first-person perspective. From the top, an overview of the factory is available (Fig. 12.5), in this case, the roof is automatically removed to show the entire layout. Furthermore, a set of viewpoints can be defined at any time for later use to facilitate the navigation.

Virtual machines, workers, and transport systems can be created through a GUI accessing a database of resources. All units are available in drop-down lists, grouped in four types (building, machines, transports, and workers; see Fig. 12.6), and they can be used as templates for creating new instances.

Units can be selected and placed in the factory in an intuitive way (drag-and-drop) and a set of commands is available to duplicate, to delete, and to find them in the factory (Fig. 12.7). A list of the units in the layout is available and for each unit some parameters can be set using the GUI.

Simulation data can be imported into the GIOVE VF and displayed within the Virtual Environment in an overlaid panel and with markers around the involved machines: This provides an easy feedback about the machine that is currently the bottleneck, highlighted with a flashing area (the rectangle below the machine visible in the Fig. 12.8).

Working in a collaborative mode (as server or client), the tool allows various users to see each other (name and picture) and to interact simultaneously in the same

Fig. 12.6 Selecting a machine template from the GUI and placing it on the factory floor

Fig. 12.7 The GIOVE VF project GUI

shared Virtual Environment (Fig. 12.9). A voice conference can be activated during the collaborative session thanks to a link to Skype™ API (as detailed before).

Each action made by one of the users is visible to the others in real time, and the access to the objects in the Virtual Environment is controlled by the application, depending on user's role and rights.

12.2.6 Integration With Other Tools

The integration of other tools with GIOVE VF is based on XML documents. The "factory definition" file defines the factory units (machines, building,

Fig. 12.8 Simulation data displayed in the Virtual Factory. Note the area around the bottleneck machine

workers and transports), whereas the “layout definition” file describes which of these units are present and how they are arranged and related to a production process. These XML documents belong to the project data, and they are used to exchange data with the other tools (Planning Table, Simulation in the Factory Constructor, and Emergency Training Simulation in Training Simulator digital activity). In this way, it is possible to import a layout from the Planning Table, to run externally the process simulation with a Web interface to eM-Plant (developed by SZTAKI, Hungary) and import the result in GIOVE VF, where the simulation data can be displayed in an intuitive way. Furthermore, it is possible to export the layout data, including information about the workers, for creating a training session to instruct the people in case of an emergency situation (like a fire) in the factory.

GIOVE VF is a clear example of how new GIOVE-based tools are created starting from the existing modules. To build GIOVE VF, a standard base application development library was used (GIOVE Viewer); then, a new “add-on” module was developed to integrate the factory data model and its related functionalities. This is the way new GIOVE tools are developed: linking the GIOVE Viewer module to inherit all the basic functionalities (often customizing and overriding them), then (if needed) developing a new add-on module to support new features. The latest version of GIOVE VF integrates an add-on module devoted to the WebDAV protocol support to exchange data within the DiFac collaboration manager.

Fig. 12.9 The virtual factory layout viewed from the perspective of two different users

12.2.7 Scalability

GIOVE VF provides a collaborative Virtual Environment where a factory layout can be designed and explored with good graphic quality. This tool is able to run on a wide variety of hardware ranging from a simple laptop to expensive VR systems (it has also been tested on a multiscreen stereo projection system with different input devices). Another interesting feature is its lightness: it needs only few megabytes to run, with no need for installation, it can be run directly from a pen drive, project data included.

On the other side, when more immersive (and expensive) technologies are available, more users can feel immersed in the factory like they really were inside it, walking though the layout with a better feedback about the final result. This is the reason why GIOVE VF uses the Immersive Integrator (Dürr et al. 2008), a tool that provides the support for a multiscreen stereo projection and for additional devices (Fig. 12.10).

GIOVE-rendering engine allows the full textured high-quality graphics, enhancing the sense of presence when exploring the virtual factory. This allows a

Fig. 12.10 GIOVE VF running on desktop VR and immersive VR systems

more complete feedback and can be well understood by unskilled people, for example, workers can discuss with the factory planner about their workplace by giving hints directly in the collaborative Virtual Environment.

12.3 DiFac Case Studies

This section presents briefly the application of GIOVE in different industrial cases of the DiFac project. GIOVE tools were applied to factory design (GIOVE VF, for COMPA factory), product configuration, and collaborative review (GIOVE Virtual Showroom, for P. Pashalidis & Sons S.A., Greece (PPS) carpets and for Prima Industrie S.p.A. (PRIMA) laser-cutting machines).

12.3.1 GIOVE Virtual Showroom

GIOVE Virtual Showroom (GIOVE VSR from now on) was developed and tested first with the PPS case, then it was applied also to the PRIMA case. GIOVE VSR was integrated as a VR tool in the Prototype Designer (Chap. 7). With this tool, it is possible to create a scene with objects grouped in a hierarchical structure, define more variants for the same objects, and define objects properties, such as color, size, position, etc.

12.3.2 PPS Case

GIOVE VSR functionalities development was initially driven by the requirements provided by PPS, a company with the need for advanced tools supporting the designers in the creation of new carpets and providing a more effective way to communicate with the customers. Designers can review new models of carpets in a

Fig. 12.11 GIOVE virtual showroom: configuring PPS carpets

Fig. 12.12 Configuring a laser-cutting machine in GIOVE VSR

GIOVE VSR collaborative session inside a realistic virtual environment and customers can see in real time the changes made by the designers to meet their requirements, so they can agree with the proposed solution and contribute to the refinement of the digital prototype (Fig. 12.11). A link to Skype allows them to talk together during the session.

12.3.3 PRIMA Case

Another scenario involved PRIMA for the configuration of a laser-cutting cell and the evaluation of possible alternative configurations (Fig. 12.12). The customer and the assembly engineer can interact in a shared virtual environment to select different variants of a machine component, to customize colors, or to check the space constraints inside a building. Users can talk during the collaborative session thanks to the Skype conference support.

Fig. 12.13 The real COMPA factory and the virtual environment in GIOVE VF

12.3.4 GIOVE VF: COMPA Case

GIOVE VF was developed against the requirements provided by COMPA scenario, to build a Virtual Environment similar to the real factory, taking into account the arrangement of machines, transport systems and workers inside the building. Information about the production process (Chap. 14) can be visualized in GIOVE VF, providing an immediate feedback about the bottleneck machine (see the Appendix in this book).

12.4 COMPA Case

COMPA S.A. (Sibiu, Romania) is a manufacturing company in the automotive sector, where machine tools, operators and some trolleys for the transportation of parts and products mainly compose the production system. The company is introducing new products (mainly components for automotive sector) almost every 4–6 months. A new setup and replanning are needed to optimize the production line. The GIOVE VF has been tested against this real industrial scenario (Fig. 12.13).

12.4.1 Creating the Factory Layout

The first step to build the virtual representation of the real factory consisted in collecting all the needed data from the real factory, the real machines and about the production plant logistics. The building and the machines were entirely modeled with Autodesk 3ds Max, photos were taken of the real objects to build textures for 3D models, and finally a precomputed global illumination was encoded in the final textures.

Once the building and any needed 3D model were ready, they were referenced in the factory definition file and made available to GIOVE VF. In this way, it was possible starting from the "green field" to create the factory layout using the GIOVE VF GUI.

For each unit class (building included), all the templates were therefore available in a drop-down list; therefore, the creation of a new unit simply required to choose the desired template in the list and to place it on the factory floor. More instances of the same machines were created using the duplication function, the same holds for trolleys and workers, and so on. The first draft of the factory layout was made reflecting the data available in the CAD drawing of the real layout provided by COMPA, running GIOVE VF in standalone mode. The machines properties were then updated by applying the information about COMPA manufacturing process.

12.4.2 Factory Layout Review

The layout draft was loaded by the simulation expert into a process simulator based on a Web interface (developed by SZTAKI, Hungary) to the commercial eM-Plant simulator (UGS Tecnomatix). The layout designed with GIOVE VF was then simulated and the results, added to the layout file, were available back again in the VF.

A GIOVE VF collaborative session was then run to review simulation data and update the layout to find a better solution. Finally, the layout was exported again to the process simulator to test the new layout configuration. In a following GIOVE VF collaborative session, human aspects could also be taken into account, simulating a brainstorming between a worker and the layout manager about the workplace.

An interesting result of this work was that the GUI configuration and GIOVE VF functionalities were better tested and improved according to the feedback from the layout designer who first used GIOVE VF and from many users who tested the interface of this tool. Many topics arisen from this evaluation will be covered in the future development of GIOVE VF, as detailed hereafter.

12.5 Conclusions and Future Work

Many users who provided their feedback, mainly about the functionalities and the GUI, have tested GIOVE VF. These data were taken into account to improve a sequence of prototypes, but some further improvements are requested.

GIOVE VF currently allows to design a production layout and then to perform the process simulation exchanging data with eM-Plant (Chap. 14). However, companies require also further services and the control over a wider range of parameters. To meet these requirements, ITIA is planning to develop a new version of GIOVE VF, adding more services allowing the integration of several other components to support the whole factory design and management. An overview of possible developments in this direction follows hereafter.

The first update required is a tool for designing factory units to make them available in the factory definition file before using them in a layout. The tool will speed up the creation of the resources database and will provide a more complete definition of machines, transport systems, human operators, and their properties. These new data will help the designer to describe the whole factory, including transport paths, piping, constraints in machines placements, and other aspects concerning both the products and the processes. The simulation model also needs to be extended and completed to better reflect the complexity of a real factory. Future GIOVE VF versions will take into account all these data, providing a proper GUI and managing the interaction between the user and the virtual factory.

Another interesting issue is the possibility to show inside the virtual factory not only the final results of a process simulation but also the product flow through machines and transport paths, the state of machines (overloaded, waiting, fault, etc.), and even workers movements (to study ergonomics improvements). All these data must be provided by proper modules integrated into GIOVE VF.

There are also other features that users requested, as the collision check among machines and with the factory building and between the user's avatar and the virtual environment.

Even if a precomputed global lighting was already applied to achieve a high graphic realism, a real-time global illumination could be more flexible and could speed up the definition of the virtual factory units.

Furthermore, a better integration with other CAD and 3D modeling software could make easier the creation of the virtual objects (buildings, machines, etc.); therefore, ITIA planned also to support COLLADA 3D file format (http://www.collada.org/mediawiki/index.php/Main_Page) in future versions of GIOVE.

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Chapter 13
Augmented Reality for Remote Maintenance

Katharina Buckl, Stefan Misslinger, Piero Chiabra and Glyn Lawson

Abstract The high rate of innovations being introduced on high-tech products requires fast and efficient approaches for information and knowledge transfer, especially in the area of service and maintenance tasks. The Digital Factory, with its methods and tools, can help to improve the service quality and at the same time reduce the costs associated with maintenance operations. The developed tool for augmented reality (AR) based maintenance supports the creation of AR-based workflows and their execution within a collaborative environment. Targeted to small and medium enterprises, the DiFac development is based on the three theoretical pillars of presence, collaboration, and ergonomics. The achieved results are continuously validated by end users and human factors experts. This chapter presents the conceptual training framework developed within the DiFac project, its realization for the task of AR-based maintenance, and the evaluation of the developed components.

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13.1 Introduction

13.1.1 Motivation

The high rate of innovations introduced on high-tech products, particularly in the sectors of machine design, instrumental goods manufacturing, and industrial plant design, forces a permanent information transfer. Among these, the continuous training of service and installation technicians is necessary to offer the most effective and efficient technical assistance to the customers. An ever increasing training quality and efficiency is required for technicians on newly developed products because of their extremely high technology and customization level.

To survive in the future market, companies must offer enhanced services to their customer covering the complete product life cycle. Therefore, maintenance services have to be greatly developed and empowered to cope with the continuous technical innovations that make the products more and more complex. The need to have more and more skilled technical service operators is becoming a real problem, because often the traditional information exchange methods and tools do not succeed in keeping up with the innovation rate of the products.

Moreover, in such a high-technological field, because of the very advanced technologies being used, quite often R&D technicians have to directly take care of the critical operations on the machines, systems, or software they have developed. They have to travel to different customers sites to support the work done by local technicians. This kind of information and know-how transfer is very time-consuming and expensive, thus not effective in a long-term perspective. Hence, there is a clear need for improved service processes for maintenance, which allow solving problems faster and with reduced cost effort (Chiabra and Masotti 2007).

13.1.2 DiFac: Digital Factory for Human-Oriented Production Systems

This necessity for improved services in the field of training and maintenance is addressed by the DiFac project through the development of an innovative Collaborative Manufacturing Environment (CME). The DiFac CME provides a framework to support teamwork in an immersive and interactive way for concurrent product design, prototyping, and manufacturing as well as worker training. This last aspect is covered by the Training Simulator.

The Training Simulator supports emergency training as well as worker training targeted to maintenance problems, specifically remote joint maintenance tasks. Remote joint maintenance is realized by the Training Simulator for remote maintenance (TSRM), which capitalizes on the use of augmented reality (AR). This innovative technology allows overlaying virtual information seamlessly with views of the real world. It can therefore provide an efficient and intuitive interface for guiding workers through their maintenance tasks.

The TSRM offers the following two main functionalities:

- Easy and fast creation and execution of maintenance procedures based on the application of AR
- Provision of collaborative functionalities for communication and desktop sharing to support the remote expert approach

The main innovation in the proposed system is a tool for the creation and execution of AR-based workflows. This tool offers a new approach for AR scenario creation and authoring, which also allows people without programing skills to create AR applications, for instance, AR-based maintenance. Furthermore, the application within the DiFac project and its human-oriented development process allows achieving another important benefit. In fact, the developed technologies were continuously validated against end user requirements as well as taking into account presence, collaboration, and ergonomics aspects.

13.2 Background

13.2.1 Augmented Reality Applications for Service, Maintenance, and Training

AR is an innovative technology that combines real and virtual information by integrating virtual data seamlessly into views of the real world. It can bring additional information to the real world at the right time at the right place. Thereby, it meets all three driving forces for the introduction of new technology in the industrial environment: cost reduction, speedup of processes, and quality improvement (Regenbrecht 2006). AR has already been successfully applied to many industrial activities, such as design, planning and production, or service and maintenance (e.g., Platonov et al. 2006; Pentenrieder et al. 2007).

In the field of industrial after-sales service and maintenance, AR technology can be used to support various tasks by superimposing work-step-specific information into the user's view of the maintenance scenario. Using databases, any kind of information can be shown to the user from simple 2D text, arrows pointing out working locations, or dangerous areas, to animated 3D models seamlessly overlaid with the real work environment, offering precise guidance through difficult service tasks (Lawson et al. 2007).

Tang showed that the use of AR in object assembly improved the task performance and can relieve mental workload on assembly tasks (Tang et al. 2003). According to the study, the time to complete the task using virtual and in 3D-registered instructions is not much lower compared with other methods. However, it resulted in a significant accuracy improvement. Thus, many industrial

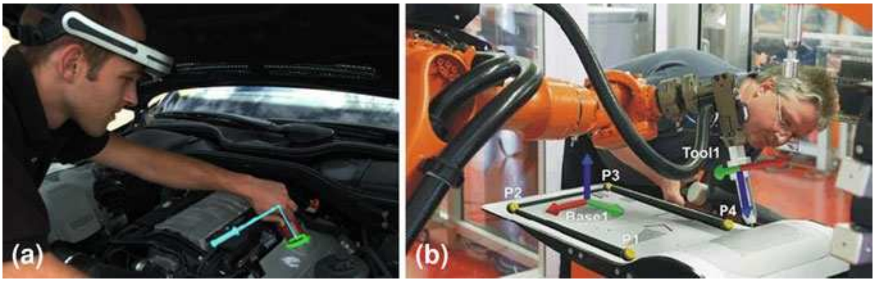

Fig. 13.1 Example application for industrial AR: **a** AR-based maintenance and **b** AR-based training at KUKA

companies already set up prototype systems where AR technology is applied to deal with the increasing complexity of technical systems.

An AR-based maintenance example is its application in automotive industry where assembly and disassembly information is superimposed onto the user's view of the car (see Fig. 13.1a). The worker is wearing a head-mounted display, which is equipped with a camera looking into the scene. Based on the current work-step, specific information on necessary tools and the single steps of an assembly process are displayed to the user, seamlessly overlaid with the real environment.

A different kind of usage for AR is constituted by worker-training scenarios. Here, additional information provided by the AR system helps the trainees to better understand the functionality of a machine. Figure 13.1b shows AR-based worker training at KUKA. The KUKA AR Viewer application eases the complexity of robot programing by augmenting the trainee's view with the different existing coordinate systems. Furthermore, the AR Viewer supports path planning and simulation of programed robot actions (Kuka 2008).

Further industrial service and maintenance applications of AR technology can for instance be found on the homepage of the German research project ARTESAS (Artesas 2004), whose main goal was exploring and testing AR-based technologies for their applicability in industrial service environments.

13.2.2 AR Workflow Systems

In recent years, several approaches have been created in the field of AR workflow systems. For the workflow component of the TSRM, previous work in the field has been analyzed to identify requirements and goals for this component. An overview of the described existing systems is given in Table 13.1.

The distributable wearable AR framework (DWARF) is a component-based framework that simplifies the development of distributed AR applications by providing reusable services for key problems in AR, such as tracking and object modeling (Bauer et al. 2001). It contains an XML-based task flow system that

Table 13.1 Overview on existing AR workflow systems

AR workflow system	Description	Main disadvantages
DWARF	XML-based support of distributed application creation	No graphical user interface
ARVIKA	Workflow authoring for maintenance	No dynamic content change
DART	Adobe Director plug-in for rapid AR application prototyping	No realistic/high-end rendering
AMIRE	Authoring of a complete AR application	Only high-level oriented static modeling
APRIL	XML-based data-driven authoring of AR applications	No graphical user interface

reacts to user input. However, a graphical authoring tool for this system would still be needed.

The German research project ARVIKA (Friedrich 2002) analyzed how AR can be used to support processes in development, production, and manufacturing. The AR system that was developed within the ARVIKA project provides a workflow engine that aims at creating maintenance applications. However, the system only provides elementary tasks to display text, images, or 3D models, and does not, for instance, allow changing 3D properties at runtime, which can be useful for various workflows.

Another approach is given through DART (MacIntyre et al. 2004), which focuses on the rapid prototyping of AR applications. The system builds on top of Adobe Director, an existing multimedia authoring system, which is extended with AR components. Thus, designers and artists who are already familiar with Director only have to learn the AR-specific parts to use DART. Although DART can be used for a prototype of an AR presentation, it is lacking high-end rendering capabilities for creating realistic 3D graphics that are needed for the commercial versions of such applications.

The AMIRE system is an AR-authoring system developed in the context of the AMIRE project (Haller et al. 2005). It enables the user to visually create an AR application by adding application components to the authoring frontend and connecting their outputs and inputs. However, AMIRE focuses on the entire modeling of an AR application, whereas for the DiFac Training Simulator context, only the dynamic model of a maintenance process is of interest.

APRIL (Ledermann et al. 2006) is an XML-based descriptive authoring language for AR. It removes a direct reference to a programing language and replaces it with a data-driven model. An APRIL application is based on reusable components that are defined using XML files, which offer a high degree of flexibility as they can easily be modified and extended.

Projects such as those described above have already made approaches in the direction of creating an intuitive AR-authoring system, but a de facto standard system for the development of AR applications does not exist yet. Grimm et al. (2002) points out that because of the complexity of AR applications, only experts are able to prototype and develop these. This is supported by the fact that most AR systems are systems developed by computer scientists to be used by computer scientists. Therefore, content authors such as designers or modelers need to work closely with computer scientists to implement their ideas, as these authors usually do not have enough programming skills to use currently existing AR systems. There is a clear need for AR-authoring environments that provide access to the medium AR without requiring programming skills or deep knowledge in the field.

13.3 Training Simulator for Remote Maintenance

13.3.1 Training Simulator

The Training Simulator aims to generally support worker training and offers several training-related applications components, among them the remote maintenance one, TSRM. To develop the Training Simulator, activities common to general training tasks were identified and described in a generic functional architecture (see Fig. 13.2 and Lawson et al. 2007).

This architecture also includes the three theoretical pillars the DiFac framework is built on. In fact, the different activities within the Training Simulator are evaluated according to presence, collaboration, and ergonomics aspects. In addressing these pillars, the different components of the Training Simulator can be improved, taking into account not only functional requirements but also human factors aspects.

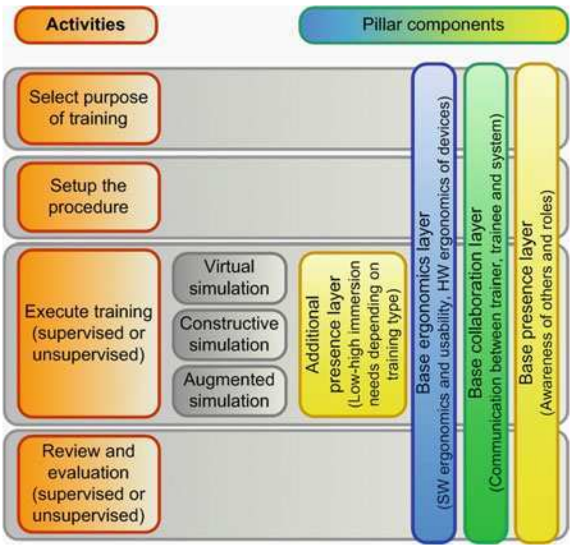

Fig. 13.2 Training Simulator generic architecture

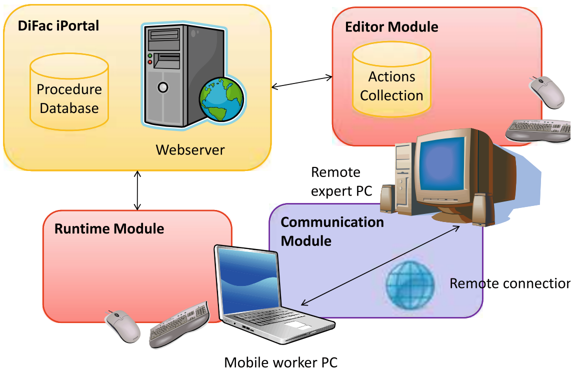

Fig. 13.3 TSRM: architectural overview

The TSRM is one realization of the generic Training Simulator architecture. It can be divided into different modules developed according to the three DiFac pillars, providing all the required functionalities (see Fig. 13.3). The system is based on AR technology, which is included in the modules for creation and execution of maintenance workflows (editor module and runtime module). Through the AR-based visualization, an intuitive interface between virtual maintenance information and the real working environment is provided. Thereby, the presence aspect can be greatly improved. Furthermore, collaboration is supported through the integration of communication functionalities (communication module) and the data exchange through the DiFac iPortal, which constitutes the single point of access for the overall DiFac system. With respect to ergonomics, extensive user tests have been performed to optimize the usability of the system and all its modules.

The functionalities and underlying technologies of the different modules are explained in more detail in the following sections. In the evaluation section, more information is provided about the performed continuous validation approach and its results in terms of iterative improvements.

13.3.2 Augmented Reality Environment

The existing AR platform Unifeye SDK (Metaio 2008) is used as a base for the TSRM.

The Unifeye SDK is a commercial software development kit for the rapid and easy development of AR applications. The Unifeye SDK encapsulates all AR core functions, such as tracking, rendering, and capturing or user interaction. It also provides the user with an application-programming interface for the development of AR applications (Fig. 13.4).

Using the available functions of the Unifeye SDK, various AR scenarios can be realized. The capturing component of Unifeye provides access to image data (still image, video, or life camera streams). The tracking framework of Unifeye contains tracking algorithms, which can retrieve the camera viewpoint for a given image using for instance marker- or markerless-tracking approaches. Given this camera

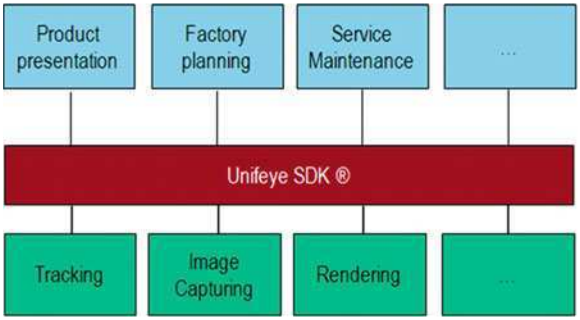

Fig. 13.4 Unifeye SDK framework

viewpoint, additional virtual 3D information can be overlaid seamlessly with the real camera image. The rendering component then visualizes the combined AR information to the user.

13.3.3 Workflow Component

For the creation and execution of AR-based workflows, a specific workflow component was implemented. Based on the analysis of advantages and disadvantages of the approaches followed in previous work in this field, a set of following requirements and goals for the TSRM workflow system was deduced.

- The system should be usable by non-programmers.
- The system should have a set of standard actions available.
- The system should consist of reusable components.
- The system should be extendable.
- The system should use open standards for data storage.

The developed TSRM workflow component is based on a finite state machine concept (Fig. 13.5). Different states are connected via transitions. In the application context, the different states are the work steps, which are called Actions. Actions are atomic components that perform different tasks within the workflow. Connections lead from one action to another. To link connections to user input, a transition condition, in other words a trigger, can be defined (e.g., a specific event characterizing an available input device). If the user triggers the required input, the condition is fulfilled and the transition to the new action is made. Entering the new action executes the action logic.

The workflow component can be divided into the following subsystems:

- *Workflow subsystem*: The workflow subsystem is responsible for managing all workflow-related information, such as actions, connections, and information about the graphical representation of the workflow in the authoring tool. The workflow subsystem can load and store workflows. Here, the well-known open-standard XML is used to store in files the workflow information about actions and connections. For executing the workflows, the scripting subsystem is required.

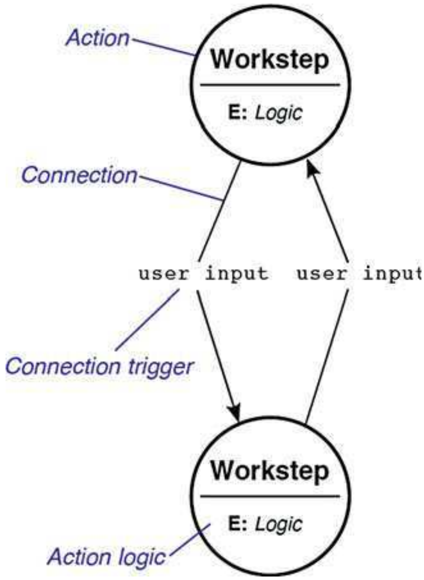

Fig. 13.5 Basic workflow model

- *Scripting subsystem*: The scripting subsystem is used for interpreting the workflow application logic. It provides the runtime system with executable code that can connect to an instance of the metaio Unifeye SDK component. The scripting subsystem is realized based on Microsoft.NET dynamic code compilation. The system can dynamically convert C# source code such that it can be executed by the.NET framework. This approach has many advantages, such as the possibility to use the full functionality of the.NET framework (e.g., for connecting to databases or using complex application logic).
- *Runtime subsystem*: The runtime system is responsible for handling the user interaction and keeping the state of the workflow. It receives an executable script from the scripting subsystem and executes it according to the user input. During execution, all devices that are connected to the system are activated and the runtime system listens to the different events of the available input devices. Currently, mouse and keyboard as well as the Nintendo Wii remote controller can be used as input devices.
- *Graphical user interface*: The graphical user interface provides the frontend for authoring the workflow logic. It uses the workflow subsystem as information source and provides the user with a view on this information. The XML-based representation of different actions and their connections is presented in a more intuitive graphical way. The authoring frontend is visualized in Fig. 13.6.

The different subsystems of the workflow component provide the necessary functionalities for creating and executing AR-based workflows. The TSRM editor module is directly provided by the graphical user interface subsystem presented above. For the workers on-site who execute the maintenance procedures, the runtime module and the communication module are integrated in a graphical user

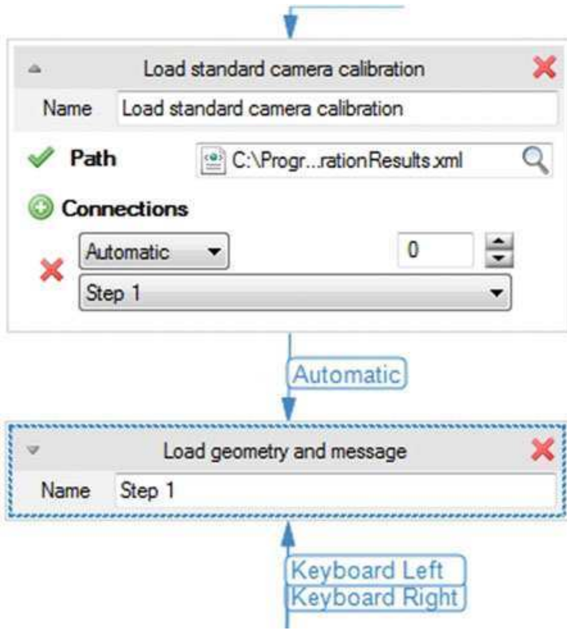

Fig. 13.6 Excerpt of graphical user interface of the authoring environment

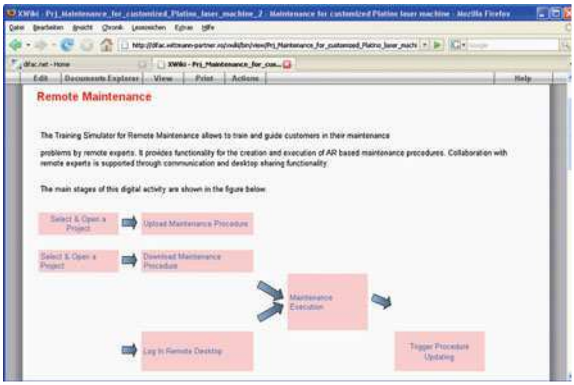

Fig. 13.7 DiFac iPortal

interface tailored to the DiFac application scenario. The user interface will be presented in more detail in the section dealing with the example application.

13.3.4 DiFac iPortal

The last module being part of the TSRM is the DiFac iPortal. The iPortal presents the single point of access for data and knowledge for all DiFac digital activities.

For each digital activity, the iPortal provides a template structure to support the startup phase of new projects concerning product design, factory planning, or training contexts (see Fig. 13.7). In the case of the TSRM, the template provides guidance for:

- Creating maintenance procedures using the AR workflow authoring environment
- Storing and accessing the procedures in the iPortal knowledge repository
- Executing maintenance procedures using the maintenance application
- Performing collaboration to support remote expert intervention

Furthermore, the iPortal organizes the necessary software tools to perform the different tasks related to the respective DiFac digital activity.

13.4 Example Application

13.4.1 Introduction

Prima Industrie S.p.A. (PRIMA) is one of the major companies working in the development and manufacturing of robotic laser-cutting equipment. The company is operating through a worldwide distributed set of centers of technical competence and marketing branches.

Within the DiFac project, PRIMA takes the role of an end user for the Training Simulator component, having a specific interest in the area of remote joint maintenance. For PRIMA's products, the increased degree of customization requires very specialized interventions for service and maintenance tasks. These tasks often cannot be performed by an ordinary service technician and thus require the skills of a maintenance expert or an R&D technician.

PRIMA's objective is to increase the operational performance by offering remote technical support from headquarters to their customers' branches located in different parts of the world. Thereby, intervention time shall be reduced and the use of resources shall be optimized. Time dedicated to maintenance support shall be saved in favor of research and development operations. In addition, overall costs, in particular travel, can be reduced.

13.4.2 PRIMA Remote Maintenance Application

As a concrete use case for the TSRM, a scenario for PRIMA was implemented. An AR-based maintenance procedure for a lens-cleaning process for a Platino laser machine was created using the workflow authoring environment described before.

The PRIMA remote maintenance application is based on the metaio Unifeye SDK and the workflow system.

Figure 13.8 shows the graphical user interface of the application. The user can load maintenance procedures and execute them using connected interaction devices. As part of the maintenance workflow, a camera can be activated to

Fig. 13.8 Graphical user interface of the PRIMA remote maintenance application

Fig. 13.9 AR view of the remote maintenance application with text and 3D virtual data

capture the real environment. Navigation through the workflow can be done via mouse, keyboard, or Wii interaction. For each work step, according data (2D text and/or 3D model data) are overlaid with the current view of the camera based on the workflow configuration. In addition, Skype has been integrated in the frontend to have direct access to communication functions for chat and voice over IP. Furthermore, a desktop sharing system can be accessed through the interface. The application is equipped with an annotation tool to provide extended interaction functionality especially for the case of remote expert intervention. For determining the camera view on the real environment, a marker-based tracking approach was used for the first prototype. It was later on replaced by the more convenient markerless tracking.

For standard maintenance procedures, which can be executed by a skilled worker on-site without the help of an (remote) expert, the AR-based maintenance application can guide the worker through the different maintenance steps. 2D text as well as 3D visual information are presented on a portable device and regularly

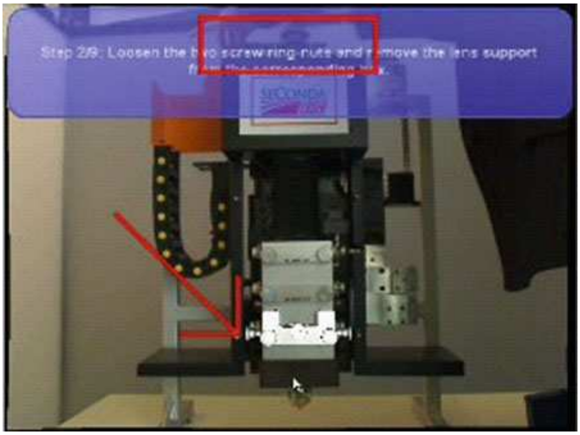

Fig. 13.10 AR view of the remote maintenance application including annotations

synchronized with a maintenance procedure database (see Fig. 13.9). For non-standard maintenance procedures, which are more complex, a remote expert is able to share the view of the on-site worker and give guidance on the current tasks. The communication tools allow for chat and voice over IP and in addition, the collaborators can use the annotation functionality to point out special locations in the current scene (see Fig. 13.10).

13.5 Evaluations During Development

13.5.1 Evaluation Approach

An important aspect during the development of the DiFac components was the continuous validation of the achieved results by the end users and other stakeholders (decision makers, technical developers, human–computer-interaction experts, etc.). An iterative development process was chosen, following the ideas of test-driven development and working according to a participatory design approach. Essential elements of this approach include:

- Attention to adopting systems to suit human capabilities
- Direct involvement of participants
- A step-wise approach

With the end users placed at the core of the evaluation process and an iterative development approach, the DiFac prototypes were frequently validated, allowing detecting and fixing problems continuously and avoiding misunderstandings of end user requirements thanks to short feedback cycles (Beck 1999; Bourguignon et al. 2007).

Next to end user validation on the functional aspects of the technology, the DiFac applications were also evaluated according to the three DiFac pillars:

VIEW of the future — DiFac

Inspectors (& Institution): Glyn Lawson (UNOTT) **Inspection No.** 3.0

Application/tool name: PRIMA remote maintenance application

Developer: METAIO **Inspection date:** 22/10/08

Note: Evaluated against tasks for interim evaluation

Technical description

Overview

The AR-based maintenance tool aims to provide support for remote maintenance technicians by presenting CAD work step information overlaid onto an image of the machinery.

Input/output devices

The system requires a marker to be placed on the machinery requiring maintenance and a camera to capture the image. The output is displayed on a laptop computer.

Task Description

The AR-based maintenance tool will support maintenance tasks on complex machinery. It will provide work step information to guide the user through the maintenance task. The maintenance technician must position a camera to identify the marker and capture an image of the machinery. This image is then displayed on a laptop, and each work step is animated with CAD parts demonstrating the required maintenance procedure. Information such as part numbers, tools required and safety considerations is also presented.

User description

The user will be a maintenance engineer, working at the client's site.

Initial Issues highlighted or observed

Summary of issues found in this inspection	Priority		
	High	Med	Low
Needs collaborative solution, incorporating voice communications, chat, desktop sharing	Y		
Use markerless tracking	Y		
Several recommendations made to improve usability		Y	

VIEW Of The Future Inspection Tool (VIEW-IT) Page -1-

Fig. 13.11 Excerpt from the VIEW-IT evaluation

presence, collaboration, and ergonomics (Lawson and D'Cruz 2009). The level of presence, according to the literature (Witmer and Singer, 1998), is evaluated using special questionnaires. The collaborative tools provided by the DiFac technologies were evaluated with respect to the current best practice guidelines for collaboration. For ergonomics aspects, a heuristics checklist was developed based on the VIEW-IT assessment tool (Fig. 13.11), which was originally developed to support the evaluation of usability, input/output devices, and VR/AR systems (Tromp and Nichols 2003).

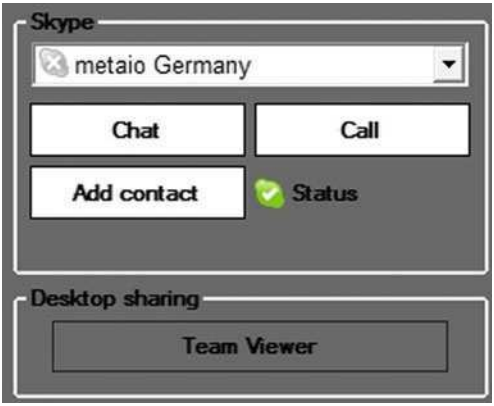

Fig. 13.12 Integrated collaboration tools in the TSRM

13.5.2 Iterative Improvements

Based on the iterative validation process, the TSRM was improved step by step. Useful functionalities for collaboration were included directly in the graphical user interface to ease accessibility. As described above, the latest version allows to directly start Skype chats and conferences as well as desktop-sharing sessions from the graphical user interface and thus no context switches to external tool are required anymore (see Fig. 13.12).

Furthermore, the editor module was restructured to simplify procedure creation and editing as well as to provide more flexibility for workflow scenarios. For instance, the first version provided only basic actions for configuration, model loading, and displaying text. In an enhanced version, the two distinct tasks, which are frequently used, model and text visualization have been combined into a single action. Thereby, the number of required actions per workflow could be reduced considerably. Furthermore, more clarity during workflow creation and editing can be provided and the working process is speeded up. Figure 13.13 shows a comparing overview of the old and new action representation.

The latest evaluation showed that the level of presence, collaboration, and ergonomics as well as the functional aspects of the application is already very well developed. Still, further improvements are possible, such as enhancing presence and ergonomics through addition of sounds and more comfortable hardware.

13.6 Conclusion

The developed innovative CME, composed of various methods and tools, is targeted at small and medium enterprises (SMEs). The CME supports collaborative working in an immersive and interactive way for three main activities in the digital factory: product design, factory planning, and training.

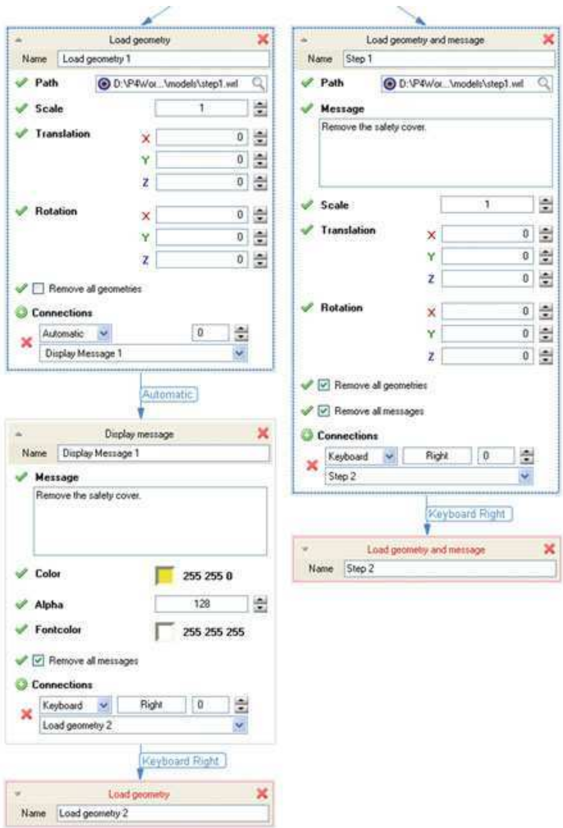

Fig. 13.13 Comparison of old model and text visualization actions (*left*) and new combined approach (*right*)

This chapter presented an application for AR-based training and maintenance, which was developed and evaluated as part of the Training Simulator digital activity.

Following the aim of the DiFac project, the developed application supports worker training in an intuitive way. Furthermore, continuous evaluation of the iteratively developed components allowed validating the functional aspects and at the same taking into account human factors in addressing the three pillars of presence, collaboration, and ergonomics. By relying on the innovative potential of AR, an efficient and intuitive interface for the guidance of workers in their training or maintenance tasks is provided, which greatly supports the presence factor. Collaboration is supported through integrated communication functionalities and helpful add-ons for annotations. For the workflow authoring environment, the focus was laid on an easy to use and flexible system, which does not require any programming skills, following the principles of usability and ergonomics. Finally, the whole system is based on standard hardware and software components, such as a standard PC, a webcam, and a Windows operating system. Therefore, it also fulfils the criterion of affordability and suitability for the target user group of the DiFac project: SMEs.

13.7 Outlook

The results of this DiFac digital activity offer many promising possibilities for the technology provider as well as for the end user.

On one hand, the results of the end user scenario can directly be exploited by the end user. Thereby, the aim of PRIMA Industrie is to further develop the prototype to a full system for remote assistance in their concrete field of application: industrial laser machinery. A final product could be available already in around 1.5 years. The main task next to the extension and improvement of the prototypical software is the preparation of the maintenance procedure content by means of the developed workflow authoring environment. The remote maintenance system could then be an additional sales element offered to the customers of laser machines. The availability of this service would then allow PRIMA Industrie to reduce the costs for maintenance tasks, thanks to an increased recourse to remote assistance. The remote maintenance service would also enhance the market appeal of PRIMA product-service solutions because the customers can reduce their own maintenance costs and increase their machine availability, thus their productivity.

On the other hand, the software functionality developed for the DiFac TSRM has great potential also for usage in other application scenarios. It can also be used for new customized AR products for design, training, or presentation. The powerful workflow engine concept based on the Unifeye SDK in combination with an intuitive graphical user interface for workflow authoring can provide easy access to rapid prototyping of AR applications. Here, the aim of metaio is to create a professional software tool that includes the functionality of the workflow engine and thus offers users in design and marketing new possibilities for product presentation and sales. Thereby, DiFac technologies extend their field of applications also to markets outside of the digital factory.

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Chapter 14
Discrete Event Simulation of Production System with Web-Based Support

Botond Kádár, András Pfeiffer and Zoltán Vén

Abstract In this chapter we review the basic functionalities and latest developments of web-based simulation and we also present the DiFac solution where the discrete event simulation is made available as a service through a web-based user interface. This solution enables SMEs to exploit the features of a powerful simulation tool as an e-service. The requirements, and both the advantages and drawbacks of web-based simulation will be also presented.

14.1 Introduction

Simulation[1] is the art and science of creating a representation (model[2]) of a process or system for the purpose of experimentation and evaluation (Gogg and Mott 1993). In other words, this implies:

[1] The Oxford English Dictionary describes simulation as: The technique of imitating the behaviour of some situation or system (economic, mechanical, etc.) by means of an analogous model, situation or apparatus, either to gain information more conveniently or to train personnel.

[2] Model is defined in the same book as: A simplified or idealized description of a system, situation or process, often in mathematical terms, devised to facilitate calculations and predictions.

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- Building a model of a real system (or a system-to-be)
- Making experiments with this model
- Creating output result for decision making and implementation support

The guideline 3,633 of the Association of German Engineers (VDI 3633 Part 2003) defines simulation as the imitation of a dynamic process within a system employing an experimental model.

The answer to the question "Why should simulation be used in factory layout, production planning and scheduling systems?" could be summarised as follows. Simulation experiments can be undertaken for several reasons but they, actually, are characterised by the same primary purpose: support decision making. As it is described in Seila (1993), all simulations are made to be able to make good decisions in some way. Good decisions lead to increased efficiency and reduced costs, which are usually two of the main goals of a company. Moreover, the aim of simulation is to derive from the obtained results conclusions that may be transferred to real systems.

Some examples of what simulation can be used for are: prediction of new system performance, evaluation of certain features in the system, comparison among several alternatives, gaining knowledge of the system at different life cycle phases, problem detection and presentation of predicted results, assessing the cost of quality and several others. Because of cost and time constraints, the real manufacturing systems cannot be used to conduct trials; therefore, modelling, simulation and animation are more widely used in this field today.

As processes to be analyzed become more complicated and complex, the more important simulation becomes with its capability of analyzing real processes. These processes cannot be covered by analytical methods and optimization processes or they may be realized only by using a large amount of resources. The aim of simulation is to arrive at neutral decisions by dynamic analysis, to enable managers to safely plan and, in the end, to reduce costs. As mentioned in Law and Kelton (2000), the greatest overall benefit of using simulation in manufacturing environment is that it allows a manager or engineer to obtain a system-wide view of the effect of "local" changes to the manufacturing system. On one hand, if a change is made at a particular workstation, its impact on the performance of the concerned station may be predictable. On the other hand, it may be difficult, if not impossible, to determine in advance the impact of this change on the performance of the overall system. The potential benefits of applying—traditional or conventional[3]—simulation in production planning and scheduling are as follows:

[3] In this context, the terms *traditional* and *conventional* simulation are used for simulation studies or experiments, where simulation is formulated to find a solution for a defined problem or evaluate a certain policy or strategy. Typically, these are situations where the objective of the simulation is to, e.g., evaluate a factory layout or the control strategy of a conveyor track. Simulation is designed for *one* purpose and the time horizon of the application is *limited* to the study in which it is realised.

- Increased throughput, decreased process times, reduced in-process inventories of parts, increased uses of resources, reduced capital requirements or operating expenses (Law and Kelton 2000; Banks 1998).
- Better overview and understanding of the system and system processes during the model-building phase.

14.2 Discrete Event Simulation

From modelling perspective, manufacturing systems are typically dynamic discrete event systems (DES). For constructing valid models of manufacturing systems and their processes, the models should represent the discrete event evolution of the system, as well as features of the underlying continuous processes.

In most manufacturing simulations, time is a major independent variable. Other variables included in the simulation are state variables, which describe what is happening in the process or system as functions of time (Banks 1998). In contrast, continuous simulation models are used for state variables that change continuously with respect to time (Law and Kelton 2000). Typically, continuous simulation models involve mathematical and differential equations that give relationships for the rates of change of the state variables with time.

In the DES approach, state variables change only at event times (see definitions below). Examples of state variables include the number of jobs waiting in the queue in front of a machine, the status of each machine on the shop floor and the location of each job in the factory. DES models are mainly flow models that track the flow of entities through the factory. The tracking is done using times at which the various events occur. The task of the modeller is to determine the state variables that capture the behaviour of the system, events that can change the values of those variables and the logic associated with each event. Executing the logic associated with each event in a time-ordered sequence produces a simulation of the system. As each event occurs and expires, it is removed from the sequence, called an event list, and the next event is activated. This continues until all the events have occurred. Statistics concerning the system behaviour is gathered throughout the simulation as well as data about the performance measures. Different probability distributions can be associated with each process to simulate variations.

A discrete event-oriented simulation program only takes into consideration points in time (events) that are of importance to the further course of the simulation. Such events may be, for example, a part entering a station or leaving it (see Fig. 14.1). Any movements in between is of little interest to the simulation so they will not modelled. Moreover, the station itself with its processing time parameter knows how long should the newly entered part be processed. As such, when the entry event occurs at the station, it instantly schedules the exact exit event for the entered part. This exit event is then automatically added and executed in the event list of the simulation engine.

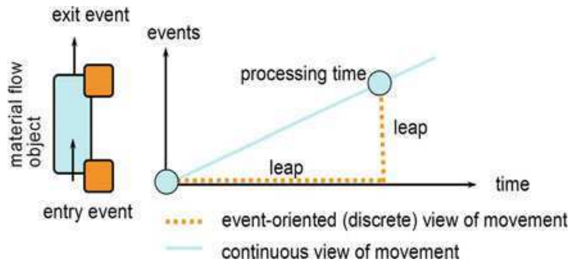

Fig. 14.1 Event-oriented and continuous representation of a material flow process, regarding events as the function of time

Finally, the most important basic terms related to the simulation modelling of dynamic discrete systems are cited and categorised here:

- Both time and state variables are defined on discrete sets.
- Over time, we have a finite number of states.

Whereas terms regarding simulation modelling are:

- *System*: a collection of entities (e.g., facility, process, etc.) that comprise a whole structure
- *State of a system*: the collection of state variables necessary to describe the system at a particular point in time
- Event: point in time where state variable may change value
- *Model*: description of the system behaviour (e.g., logical relationships)
- *Simulation*: usage of computer to evaluate numerically a model
- *Emulation*: the static simulation model without the rules that define the internal dynamics (e.g., there is no dispatching rule inside the simulation that tells a workpiece which is the next station).

14.2.1 Steps and Life Cycle of a Simulation Study

Based on the steps required for a simulation study defined by Banks (1998), the simulation study must contain the following phases (Fig. 14.2):

- *Problem formulation* and *objectives*: Define the problem to be studied, including a statement of the problem-solving objective.
- *System definition* and *model conceptualisation*: Abstract the system into a model described by the elements of the system, their characteristics and their interactions.
- *Data collection*: Identify, specify and gather data to build the model.
- *Model building* (or translation): Reproduce the conceptualised model using the constructs of a simulation language or system.
- *Verification* and *validation*: Establish that the model executes as intended and that the desired accuracy or correspondence exists between the model and the system.

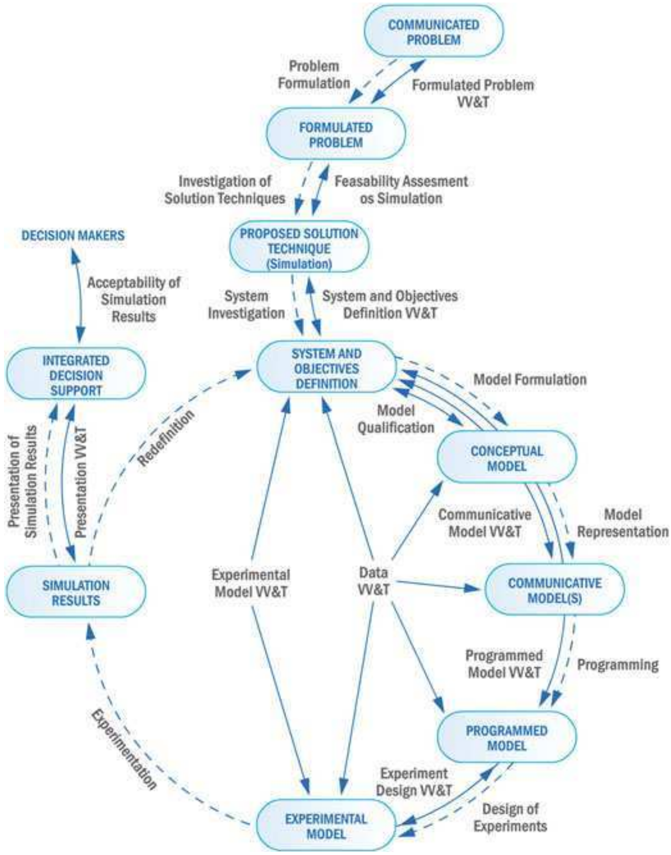

Fig. 14.2 Steps and related activities in a simulation study (based on Banks 1998)

- *Experimental design*: Design the simulation trials regarding the objects formulated at the beginning of the study.
- *Analysis*: Analyze the simulation outputs to draw inferences and make recommendations for problem resolutions.
- *Presentation of simulation results* and *documentation*: Supply supportive or evidential information for a specific purpose.
- *Acceptance* and *implementation*: Fulfil the decisions resulting from the simulation.

According to Law and Kelton (2000) and Kádár (2002), the previous sequence has to be applied in an iterative way because the execution of a simulation study is a cyclical and evolutionary process. The first draft of the model will frequently be altered to make use of in-between results and generally the final model can only be achieved after several cycles.

14.3 Digital Factory and Simulation

The concept of the Digital Factory (DF), i.e., the mapping of all the important elements of the enterprise processes by means of Information and Communication Technology (ICT) provides a unique way for managing the problems that enterprises face in today's changing environment.

According to Westkämper et al. (2004), the Digital Factory concept can be understood as a framework of digital models, methods and tools, such as simulation and 3D-visualization, which are integrated through a comprehensive data and module management system. Additionally, the concept provides better support in the handling and execution of planning processes. In a broader sense, the Digital Factory concept can be regarded as an integrated synthetic manufacturing environment to enhance all the levels of decision and control.

Moreover, as reported in Monostori et al. (2005), one of the most promising approaches towards the future of manufacturing is digital enterprise technologies, i.e., "the collection of systems and methods for the digital modelling of the global product development and realization process in the context of life cycle management" (Maropoulos 2002). Five main technical areas are outlined by the authors as cornerstones for realizing digital enterprises:

- Distributed and collaborative design
- Process modelling and process planning
- Production equipment and factory modelling
- Digital to physical environment integrators
- Enterprise integration technologies

Computer-aided modelling tools are and will be applied for designing complex products and for creating scalable virtual representations of entire factories that include buildings, resources, machines and equipment. Planners and designers can use the information from Digital Factories such as this to obtain dramatic time and cost savings for the design of new facilities and the operational management of existing ones (NN 2004).

14.3.1 How Digital Factory Concept Fosters the Application of Simulation?

Simulation is one of the main technologies used in the DF concept. This is a powerful tool often applied to the design and analysis of complex systems. As simulation models have high levels of detail, the amount of simulation relevant data contained in the Digital Factory (i.e., mapped from the manufacturing ICT systems) is considerable. However, there is also a huge amount of data which is irrelevant for simulation modelling.

The data can be separated into four blocks: (i) simulation relevant, (ii) irrelevant data, (iii) directly usable and (iv) indirectly usable data.

14.3.1.1 Simulation Irrelevant Data

Simulation irrelevant data are the data needed only for calculations or evaluations required for planning in the Digital Factory. Examples for simulation irrelevant data are cost information, detailed product information, manufacturing accessories and the process graph.

14.3.1.2 Simulation Relevant Data

Simulation relevant data are the data needed only by the simulation software. Control logics, specification and assignments of detailed shift models, stochastic distributions, routing information and experimental data (warm-up and simulation time etc.) are the major components of simulation relevant data.

14.3.1.3 Directly Usable Data

Data that can be exported from the Digital Factory without further manipulation are called directly usable data. Examples are bill of materials, structural information (resource locations and other layout information), scrap and rework fractions, machine setup and downtimes and buffer capacities.

14.3.1.4 Indirectly Usable Data

In addition to directly usable data, data also exist in the static manufacturing model as well as in the simulation model, but with different levels of detail. Examples are process and labour times that are used with mean values for static calculations, shift models without explicit resource allocations for resources operating during breaks or additional hours per day, detailed production schedules and work plans.

Completing the above-described four-data categories, Son and Wysk (2001) emphasize that the information included, which is commonly required for both traditional simulation and simulation for shop floor control, can be grouped as *static information* and *dynamic information*.

- *Static information*: The set of static information in a simulation includes physical and logical data pertaining to the shop, as for instance, layout and resource information.
- *Dynamic (time-varying) information*: Dynamic information is characterised by the temporal evolution of the objects in a system in terms of the changes of states they undergo in response to interactions with other objects inside or outside the system. For instance, dynamic information in the simulation can be used to define part flows and interactions with resources as well as random part

arrivals to the system. Given a certain set of static information, different system configurations can be implemented using alternative dynamic information.

As it was previously defined, data collection and model building considerably contribute to the overall expenditures of a simulation project. Both tasks can be simplified by using data gathered for static calculations and speeding up the model-building process through an appropriate *simulation interface* that makes possible automated simulation modelling. The simulation module of the DiFac framework applies such an automated model building. The details of this will be described in the following parts.

14.3.2 Model Building and Model Translation

DES has been applied to manufacturing for about 40 years (Randell 2002). However, for most of that time, it has been the exclusive domain of a few specialists, remote from, the manufacturing engineers. This is very much the case today as well, although the gap is getting smaller. Simulation has flexibility in the sense that it can handle several different types of systems in different details; however, the price paid for flexibility is that simulation results depend on the personal experience and intuitions of the simulation analysts.

Traditionally, simulation has been applied to the long-term planning, design and analysis of manufacturing systems. These models have been termed "*throw away models*" because they are seldom used after the initial plans or designs are finalized (Thomson 1994). As opposed to the "traditional" use of simulation, Son and Wysk (2001) proposed that once the system design has been finalized, the simulation that was used for evaluation could be used as the basis for system control. Moreover, simulation is created by using neutral system *components,* i.e., they made efforts to build simulation models for shop floor control, generated automatically. This approach has been illustrated as part of the RapidCIM project (Son and Wysk 2001) and has been successfully implemented in some test labs.

Another problem is the exchange of *system logic*. Application integration partially solves that problem, but a *neutral modelling language* that is capable of describing the systems logic would solve both the problem of exchanging models between DES tools and the exchange of logic in between DES systems and other software (e.g., simulation tool and manufacturing execution system, Randell 2002).

Hitchens (1989) presents a *life cycle* approach to the *simulation* and *emulation* of automated systems. The approach uses conventional discrete event simulation in all the phases for different purposes and *reuses* the *model* from stage to stage. And thus, regarding simulation from the project point of view, a distinction is made between simulation and emulation. Simulation is generally applied in the early stages of a project, whereas emulation is applied during the detailed design and implementation phases.

14.3.3 Web-Based Simulation

Hosting a simulation engine on a server and providing simulation services for different clients is not a very new idea. Whitman et al. (1998) presented possible Web-based simulation systems following different client–server architectures. It also mentioned the possibility of using commercial simulation tools in these architectures and the methodology to build such a system.

The developments of the Web-based simulation are strongly connected to the development of the Java language. One approach develops a new simulation language using Java, whereas the other approach ports an existing simulation language, such as GPSS, and creates it in Java (Whitman et al. 1998). Several Java-based simulation systems, such as simJAVA (Kreutzer 1997) and Silk (Healy 1997), were developed at the end of 90s.

As to the topology viewpoint of the simulation, it should be highlighted that the structure as well as the components of the modelled system and the logic of functioning are all fixed in the simulation model. Clearly, this makes building, more precisely, modifying and maintaining larger and more complex simulation models difficult. A better solution is provided by the Web-based simulation approach where the instance of a simulation model is created at run-time out of a database or a descriptive file (e.g., XML file). Such kind of models are also called generic simulation models, with the main distinguishing feature being that both the description of system structure and system parameters are stored outside of the simulation model. The data are only read and interpreted when the individual simulation model is generated (Sihn 2002).

A simulation model can be developed on the basis of the above structure to represent an existing production system. This instantiated model can then be used to answer production- and scheduling-related questions. The users of the simulation model are not expected to be simulation experts and they are provided with custom-made graphical user interface (GUI) through which simulation runs and analyses can be triggered (Andersson et al. 2007).

14.4 The Web-Based Simulation in the DiFac Framework

The Factory Constructor constitutes one of the main components of the DiFac framework, presented in Introduction of the book. The aim of this module is to support the engineers in the factory layout design. The Factory Constructor was designed to construct a 3D plant and has the capability to emulate its operations. Different factory work groups are able to share the same DF resources and interact and cooperate in the virtual environment. The dynamic analysis of a factory layout is carried out by the Web-based simulation module of the Factory Constructor, and the results of the simulation are visualized in the virtual reality environment described in Chap. 12.

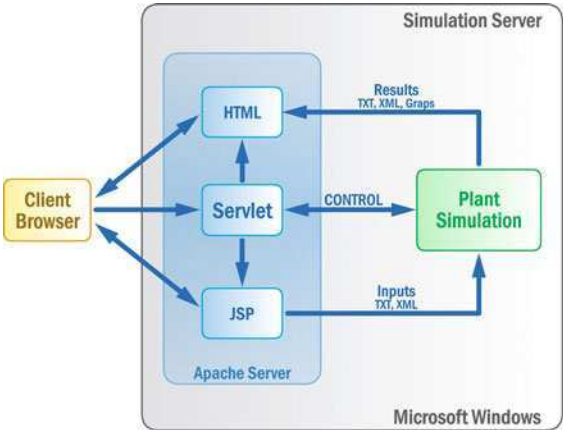

Fig. 14.3 The architecture of the DiFac's simulation module

The main objective of the simulation is to analyze the manufacturing processes in the designed layout and to locate the weak points of it with special respect to the flow of the material and the throughput of the overall system. The results provided by the simulation module of the Factory Constructor are analyzed in a collaborative way and thus they will support the decisions about the new design.

Several different solutions already exist to pass the results of a factory design tool to a simulation tool; however, these solutions are not fully automated and all of them need high expertise. The main innovation of our solution is the automatic integration of layout design and simulation environments. In the proposed architecture, the simulation module is functioning as a "black box" and the simulation model is built automatically on the basis of the data provided by the layout planner system. Aggregated results of the simulation runs are presented in a Web-based application and are further used in the collaborative decision-making process.

To help the configuration of the simulation model and to support the evaluation of the simulation results, a simulation configurator and evaluator (SCE) was developed. This module serves as a simulation cockpit and constitutes the bridge between the simulation and the other parts of the Factory Constructor (Introduction and Chap. 12).

14.4.1 Architecture of the Simulation Module

From the functional point of view, the simulation is integrated into the framework according to functional steps of the factory-planning stages. After the creation of the layout and the static 3D visualization, provided by the Layout Editor, which is the other main component of FC and is detailed in Chap. 12, a simulation analysis of the manufacturing processes can be initiated.

The simulation module is based on the "Plant Simulation" module included into the Siemens PLM software suite and it can be used in two different ways.

Fig. 14.4 The input and output of the simulation module

Having a Plant Simulation license, the simulation model can be used with the user interface developed inside the commercial simulation software. Without the Plant Simulation license, the simulation model can be used through a Web interface as a service. The architecture of the Web application is presented in Fig. 14.3.

14.4.1.1 Main Data for Plant Simulation Module

The main features of the Simulation module are as follows:

- Both the Simulation and the SCE provide support for input/output data inspections.
- The Simulation module provides a default resource library that contains general resource objects that are mapped to the resources of the Factory Constructor.
- The Simulation runs the simulation models with predefined dispatching rules.
- The Simulation has short response time, making possible multiple model runs.
- The inputs and the results of the simulation runs are exported in a common XML data file for collaborative decision making.

The inputs and the outputs of the simulation module are presented in Fig. 14.4. To meet all the requirements for a flexible simulation system, we applied the structure presented in Fig. 14.4. The data related to the layout of the factory are originated from the results of the layout design, whereas the data related to the "dynamical" part of the analysis (e.g., the capability and availability of resources, calendars, process plans, process routes, dispatching rules, etc.) sequences and other logistical constraints are stored in the database of the simulation module. All these data are specified on the basis of the production-related database of the companies that use the Factory Constructor. Using the SCE, simulation parameters can be initialized and simulation runs can be executed. These modifiable parameters include the processing time, setup time, transportation time, number of machine types for a specific operation, the time window of the simulation, the lot sizes in which the parts are carried from machine to machine and the number of the production orders entering the layout in one day. In the simulation model, the material flow of the shop floor is driven by the products and the product lots passing one-by-one through the operation that are necessary to manufacture them.

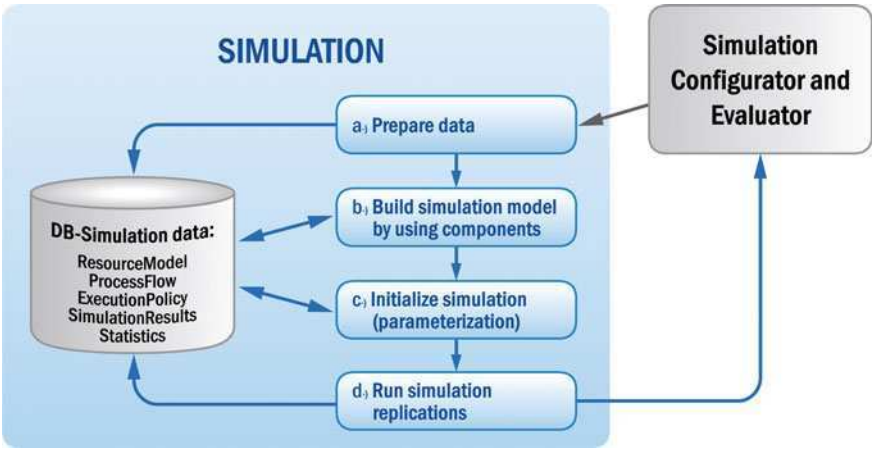

Fig. 14.5 Architecture and the main process flow in the simulation module

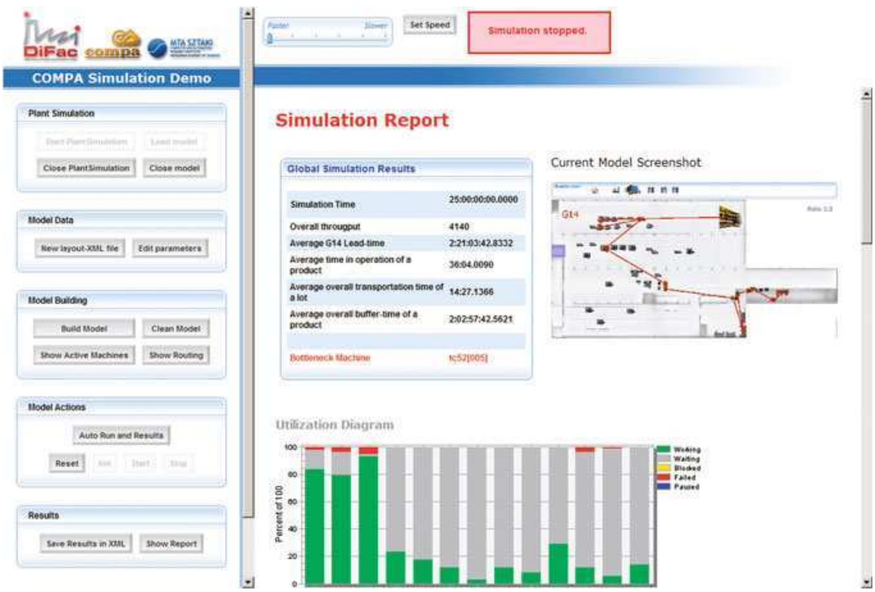

Fig. 14.6 Simulation-collected statistics is presented in the user interface

Modelling real production systems frequently brings up the problem of handling a lot of resources in a simulation model. The simulation models are always automatically created from the predefined modelling objects library, and their parameters are initiated with the layout data and the parameters passed by the SCE.

The automatic generation of the model is followed by the initialisation phase (phase c in Fig. 14.5). In this phase, besides classical parameter settings, the procedure involves the generation of input-parameter-specific model components (entities, such as products, operators, etc.). Contrary to the previous phase, this one is carried out for each simulation replication.

The simulation runs are repeated until the required number of replications is obtained (phase d in Fig. 14.5). In the last phase, the results are evaluated by using the evaluation criteria and the results of the evaluation process are interpreted by collaborative decision makers of the Factory Constructor. In the DiFac validation case study, the main criterion was the throughput of the layout, namely, the daily number of the parts processed in the model. The evaluation criteria are always defined in the decision support sub-system of the DiFac framework, which is out of the scope of this chapter.

14.4.1.2 Using the Simulation Module in DiFac

There is a sequential process-workflow that should be carried out during the on-line simulation study. This process workflow is supported by the GUI of the SCE by enabling only the operations in a predefined sequence of the required workflow. The functions of the simulation module are available in the form of different buttons on the Web-based user interface Fig. 14.6.

When the simulation run is finished on the server side, the results of the simulation are automatically displayed in the simulation Web interface. The statistics collected during the simulation run is presented in the Web interface in the form of tables and graphs. In the current settings, data about the throughput, average lead-time, the use of the resources, the times spent in the process and in the buffers are collected in tables as shown in Fig. 14.6. The simulation module also identifies the bottleneck machine in the system. In the case the user wants to perform a new simulation study, the process can be started from the parameter settings with the same layout or even from the very beginning with the import of a new layout.

The last step of the simulation study is always the save process. All the results can be saved in the common XML file and this file can be again imported in the Layout Editor where the results of the simulation are presented in the virtual environment.

14.5 Conclusion

The work presented in this chapter has been performed in the frame of the DiFac project and constitutes a part of the Factory Constructor component of the DiFac framework. The software supports the design and analysis of factory layouts, incorporates the Planning Table (see Chap. 11), the Layout Editor (see Chap. 12) and the Simulator three separate components and requires a sequential step-by-step usage of these components.

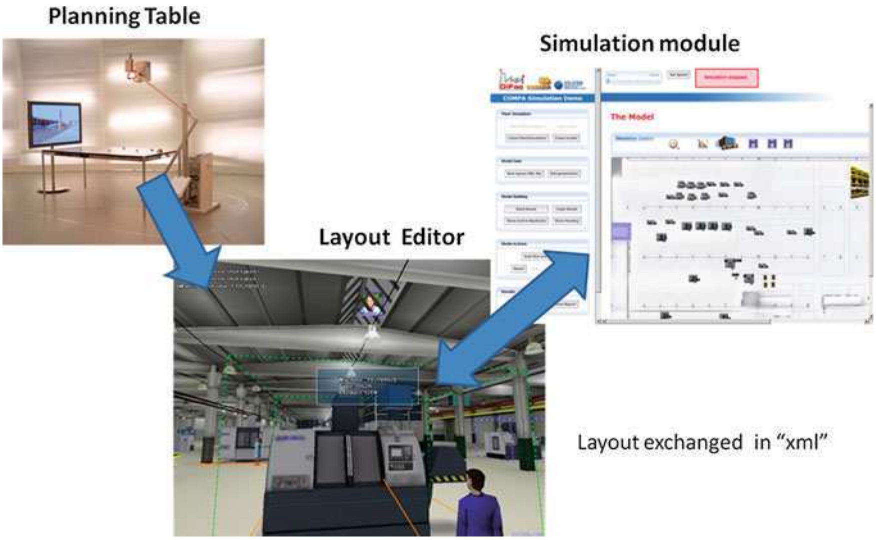

Fig. 14.7 The connection of the layout editor, planning table and simulation in the DiFac Factory Constructor

Whereas the design parts of the Factory Constructor, namely, the Layout Editor and/or the Planning Table, support the static design of a factory in a 3D environment, the third component (Fig. 14.7) constituted by the simulation module enables the analysis of the dynamic behaviour of the designed factory. The backbone of the DiFac Simulation module is provided by the commercial software Plant Simulation and the simulation functionalities are provided through a Web-based user interface.

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DiFac Industrial Case Studies

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Implementation of a Prototype of ERP–RFID Interface for the Swiss Luxury Manufacture

Matteo Lanini, Luca Canetta, Martino Casanova, Eric Müller and Pierre-Yves Voirol

Company Profile

	Company data
Name	SolvAxis SA
Address	ZI de la Suze, CH–2605 Sonceboz–Bienne
WWW	www.solvaxis.ch
Year of foundation	1987
Number of employees	>120
Industry	Independent software vendor
Products	Enterprise resource planning software
Markets	Europe with progress being made in North America and Asia

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Founded in 1987 under the name of ProConcept SA by three passionate visionaries completely oriented toward the best of new technologies, the company established itself over the years and through its growth as a robust and reputable company. The company independently designs, develops and distributes its business management integrated software, ProConcept ERP. In the course of 20 years it has built a strong position on the ERP market in Switzerland with over 1,000 sites implemented. In 2009 the company unveils its ambition of becoming a leader in providing management solutions to Swiss SME's. In order to support this new objective, the company becomes SolvAxis SA and expands its product portfolio by offering other ERP solutions. SolvAxis SA sees to the implementation of its applications, training, and follow-up and maintenance for these activities through its team of professional consultants. These consultants are respected for their expertise in business management, as well as for their experience in this field; they are the ones who take on the total management of projects, while benefiting from business and management advice as the applications are deployed Figs. 1–23.

SolvAxis SA is present throughout the Swiss market, and accompanies its customers wherever they might be in the world (China, Japan, United States, The European Union, etc.).

Reasons for Adopting DiFac Solutions

Problem Assessment

In this case study we present the implementation of a prototype of ERP–RFID interface for a Swiss Jewel company (afterwards called Jewel Company) focused on high-end luxury market. The prototype has two objectives: the first is to acquire RFID knowhow through a pilot project and the second concerns field test of the ProConcept data interface.

The Jewel Company has already been using an RFID-enabled system for the optimization of point of sales (POS) operations, in particular for inventory and selling operations on finished goods such as watches and jewels. The added value of an RFID infrastructure consists in preventing losses of highly valuable goods.

The RFID system was composed by the ERP (Proconcept), a third party application, to locally manage the RFID transactions, and some RFID hardware including readers, antennas and tags. After a pilot period, it was planned to extend the RFID solution to all of their boutiques and other enterprise sectors, but, although the solution was developed correctly under the technical aspect, the roll-out was temporarily suspended. In fact, one of the most limiting aspects has been recognized in the scarce adoption of the new procedures by the employees, mainly for the following reasons:

- Despite the actual gain of time for the inventory, other operations have been perceived as being more complex and there was not apparently any added value;

- The manipulation of the goods, as originally planned, did not guarantee the permanent association of the RFID tag to the tagged object because the label was removed when a customer was wearing it;
- The users did not interact directly with the ERP but with an intermediate application.

Other known systems issues were:

- The inefficient synchronization of goods data along the system (ERP only gather data from third party application which had his own local database);
- The RFID infrastructure was not extended to all the enterprise's units.

Before undertaking any further expansion to the remaining units, required improvements and reflections were mandatory.

The mentioned scenario is an ideal substrate for the development of our prototype and to verify the advantages of the proposed solution.

Objectives and Strategy of the Prototype

The objectives of the project are hereby summarized:

- Create specific RFID know how for Solvaxis-Proconcept through the implementation of a prototype;
- Test the developed ERP–RFID interface in a real case (as generic, flexible and human oriented as possible);
- Implement a prototype and analyze the key factors for the identification and the implementation of an RFID system minimizing risks and threats.

Moreover, the prototype must fulfill the following end-user requirements:

- Define optimal procedures to introduce RFID technologies in the high-end luxury market (borrowing and presentation to customer);
- Improve the employees acceptance of the particular tagged items handling procedures;
- Improve traceability of the goods;
- Minimize costs and counting errors by improving the inventory time (similar products might have very different value);
- Improve the efficiency and the quality of the service.

The strategy adopted for the achievement of the mentioned goals has been the identification and development of a prototype for just one application where most of the typical operations are present, thus minimizing the risk on the normal operation and facilitating the adoption of the RFID technology.

DiFac Solution

The DiFac solution will be the implementation of an ERP-RFID interface as generic, flexible and human oriented as possible and its test in a real case.

Case Assessment

Strengths	*Weaknesses*
Proven interesting and "profitable" item-level RFID application in jewellery	Performance of the previous RFID applications leads to employees skepticism.
Availability of RFID infrastructure (currently not exploited)	Current system implementation do not simplify inventory management
Opportunities	*Threats*
Possibility to leverage previous investments in RFID infrastructure Inventory process analysis and redesign	Wide field of application, necessity to focus on a meaningful application to successfully roll-out the project.

Process Analysis

The existing processes of the Jewel Company have been analyzed and the material flow has been mapped (single parts, semi finished or finished goods). The following chart summarizes the ERP domain limits and the manufacturer's units that could benefit from the ERP's introduction. The arrows represent the material flow and the line thickness indicates the critical paths in terms of parts volume transferred per time.

There are two external elements of the system: customers and suppliers. The suppliers are temporarily excluded from the ERP system because of their small size and large quantity: they are in fact numerous, more than 300–most of them are specialized artisans. It will therefore be difficult to introduce them to the RFID technology in order to get control on their internal activities. The artisan's parts are warehoused differencing them in three stocks: watches parts, semi-finished parts and finished goods stock.

The final assembly process usually concerns the watches, which are differentiable by materials, body, internal movement and wrist. These parts are picked up from the row parts in the warehouse. The finished parts may be idle stocked in the warehouse or directly sent to the stock sale's points (POS). The sales and the after sales process take place in the boutique. There, the customer has the possibility to buy jewels and in particular cases also to borrow it for special events like galas and fashion shows. A client might also request a customization, therefore the product returns to the production site and, when the jewel is adapted, it is sent back to the POS ready for the delivery.

Apart the normal operations, a very important activity along the year are exhibitions. Most of the company's energy is conveyed in organizing and participating in these events. During those occasions, most of the jewels distributed worldwide are exposed all together. This process is hereby described.

The various worldwide distributed POS do a local inventory, check and send the products to the main POS where an entrance inventory is performed. Then the items are collected and sent to the exhibition's place where another inventory is necessary.

During the exhibitions the products, that exceed the number of thousands, is exposed on trays over three stands. Every evening a detailed inventory is

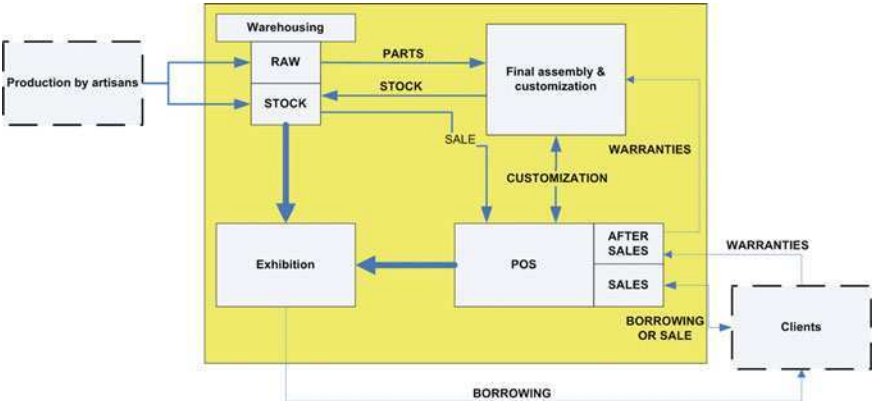

Fig. 1 Process analysis

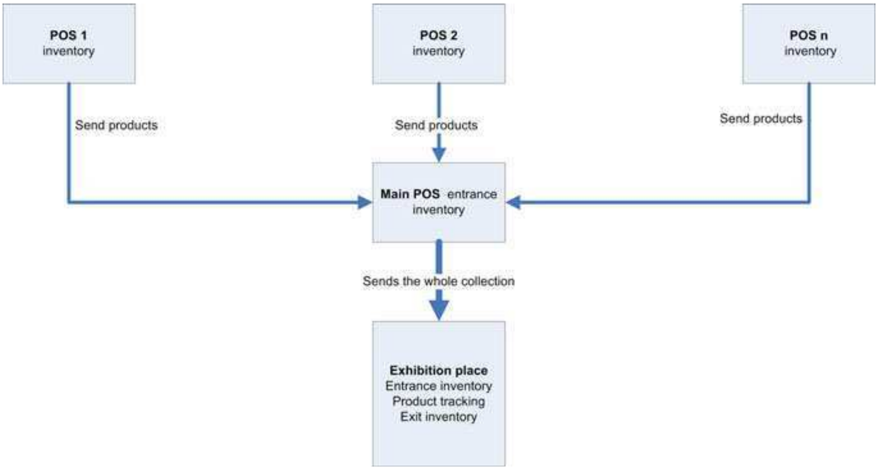

Fig. 2 Jewels collections process before (and after) the exhibitions

requested. Therefore, an RIFD system would be helpful to permanently track the items and to:

- Know in which stand a specific item is exposed (might vary) in order to improve efficiency and quality of service;
- Improve visibility and reduce risk of losses;
- Avoid theft;

At the end of the exhibition an exit inventory is performed. The products return to the headquarter where the items are inventoried and eventually they are redistributed to the boutiques.

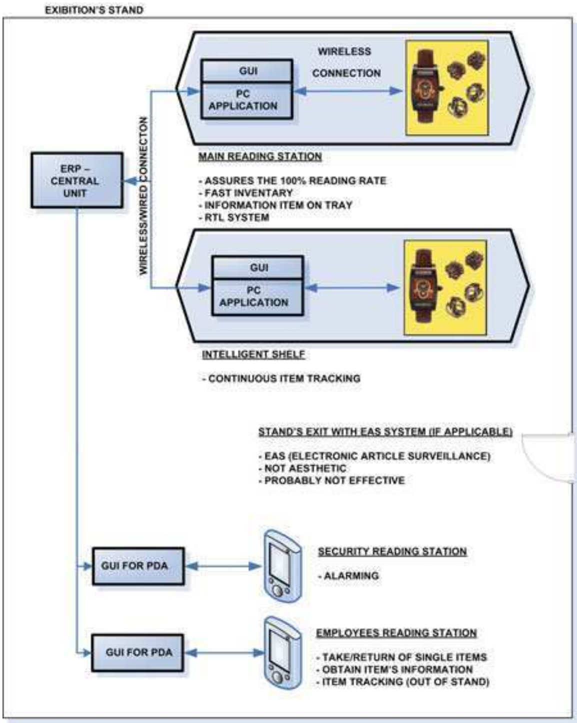

Fig. 3 Project proposal

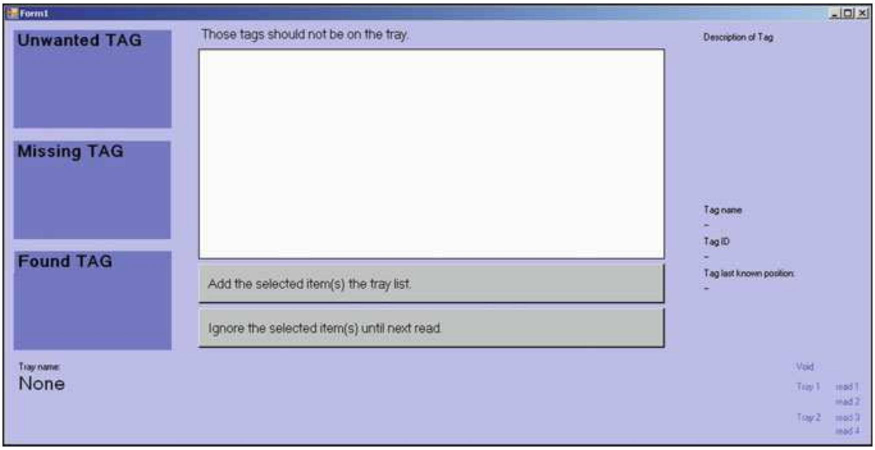

Fig. 4 GUI starting print screen

Currently, the exhibition preparation is very time consuming because many inventory have to be carried out by hand, counting and identifying one product after the other.

Project Proposal and Development of the Details with the Client

The best application for the prototype highlighted by the process analysis has been the exhibition because it represents a company microcosm. In fact, the RFID technology could be very useful in shorting the inventories time and allowing the products tracking. In this way the employees might understand the benefits of this technology and afterwards it will be easier to extend the infrastructure to the various boutiques.

To reach an appreciable result compared with the actual situation it is expected that the scanning procedure currently in use should be modified, increasing the reading capability of the tags and making the interaction between the user and the system easier (human oriented). The suggested solution foresees the continuous monitoring of the items that could be realized in the future by means of intelligent trays identified by means of an active RFID tag and with an on board passive tags reader. As it has been observed that during the fair period there is a difficulty in following the trays that are frequently manipulated and moved along the stand, the priority will be given to the real time location (RTL) of the trays and then to the identification of the items on them. The proposed solution is presented in the next figure.

From the security's point of view it is assumed that a tag might not be recognized at the stand's exit, therefore it is planned to implement an alarm system like the Electronic Article Surveillance (EAS) which is able to alert when a jewel is removed from a pre-assigned position without authorization.

Choice of the Components

Nowadays the RFID technologies used for jewellery applications are LF (125 and 135 kHz), HF (13.56 MHz) and sometimes UHF (860–960 MHz).

To develop the prototype no purchase of component has been necessary because both the RFID infrastructure and ERP were available at the jewel's manufacturer and the middleware has a free licence when not used commercially.

The decision has been to use the pre-existent HF RFID infrastructure, to tag all the jewels and to develop a user friendly RFID/ERP interface able to automatically share and filter the data collected from the RFID tags with the ERP system. One method to obtain this result is to use a middleware, a software layer that sits between the RFID readers and the ERP readers.

Fig. 5 GUI reading tray 1

Personalization of the Critical Parts

In a project, mainly when the components are given, a personalization of crucial parts must be performed. The encountered problems and their implemented solutions are hereby described.

- *Trays optimization and tags positioning*: The trays, which holds up to some dozens of items, are made of plastic covered with velvet. It has been verified that the tags reading is problematic because they are not always identifiable. In particular a random placement of the tags did not guarantee them to be always readable. Therefore, the tags positioning must be done carefully for example using dedicated slots in the trays in order to space metallic objects.
- *Tag optimization*: Until now, the tag was placed inside a cardboard and attached to the item through a wire. It can therefore happen that the tag is hidden by the jewels.

  In fact, due to its physical characteristics, metals are the first tags enemy, as they could make it unidentifiable causing detuning–reducing its performance (e.g. reading range)–and shielding it. To avoid this problem other solutions like the use of dielectric spacer between the metal and the tag or the use of a tag less sensible to metal could be taken into account.
- *Graphical user interface (GUI)*: Employees at the POS should be motivated in the use of a innovative technologies like RFID facing them with an easier and intuitive system. This is the reason why the new GUI must be kept as simple as possible and should include the following features:

– Permits the employees to perform their work faster and in the easiest way,
– Introduces the least possible number of operations that the employee are not used to make,
– Will not include unnecessary data like the unique identification code (UID) of the tags or other data available through the RFID system.

The solution is a GUI with drag and drop options that present only the selling and tracking information. A first prototype without the selling information is hereby presented:

Obtained Results

This solution, compared with the previous system, allows a more efficient management in terms of ease of usability of the system (human interface) and of identification and localization of the products.

SmartBrick: Intelligent Web Platform for Multination Industrial Use

Claudia Redaelli, Myrna Flores and Lorenzo Sommaruga

Company Profile

	Company data
Name	CEMEX
Address	Romerstrasse 13,2555 Brugg b. Biel, Switzerland
WWW	www.cemex.com
Year of foundation	1906
Number of employees	45,000 distributed in more than 40 countries
Industry	Construction
Products	Cement, ready mix, aggregates
Markets	Global

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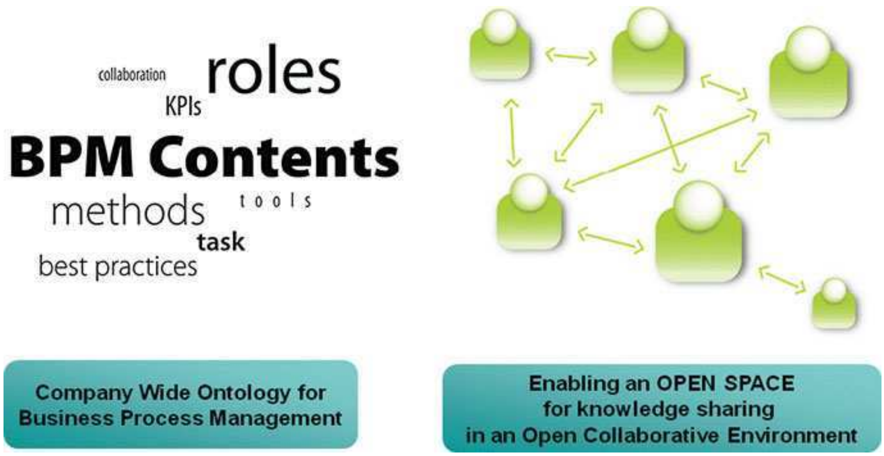


Fig. 6 SmartBricks main objectives

Reasons for Adopting DiFac Solutions

CEMEX is a global building materials company, the world's largest building materials supplier and third largest cement producer, providing both products and services to customers and communities in more than 50 countries throughout the world. Initially when CEMEX began acquiring organizations around the world during 1990s, organizational leaders realized that organizations best practices were not frequently shared. Best practices usually refer to proven techniques or methods that have provided efficient and measurable economic returns. Some identified reasons against implementing best practices from one CEMEX location to another which were the differences in culture, processes and the lack of a friendly user tool that can enable employees to share their knowledge. Thus, CEMEX faced that challenge, the need to deploy a new tool to enable employees to share best practices in a simple way to optimize its operations at a global level.

Problem Assessment

Competitive companies need to evolve into knowledge-based organizations by motivating and rewarding specialists and creating a vision that can unify an organization of specialists. In such context, SmartBricks, the web 2.0 prototype developed in SUPSI and tested in CEMEX, focused on enabling CEMEX business process management (BPM) specialists to share information and knowledge by exploiting web 2.0 and semantic web technologies. The main objective, as shown in Fig. 1, is to catalyze the development of skills to be deployed in new process improvement projects by allowing the following key functionalities: search, obtain, use, improve and share new knowledge globally in an open collaborative space that provided web 2.0 functionalities. Relevant contents will be easily found by the use of tags and specialists co-authoring contents.

Objectives

It was identified that a new tool was required to embrace the different layers in which different stakeholder's interests, needs and knowledge are reflected for the same and different process. In the current scenario, BPM specialists could be considered as "passive consumers" of business process contents, who can evolve to be "active contents as developers" using web 2.0 technologies. These contents can be generated following the open source philosophy in an open way through new forms of interaction producing the emergence of collective intelligence that could provide multiplying effects. Open is twofold: on one hand it refers to the way of content generation by users, and on the other hand it refers to the possibility of enabling distributed knowledge for to workers to interoperate. Web 2.0 refers to an improved form of the traditional world wide web where communication tools and social networking, stimulates and optimizes online collaboration and sharing among users.

DiFac Solution

The main selected elements during the requirements phase for the BPM SmartBricks prototype are: BPM Wiki, Training, Methodologies, Best practices, Business process architecture (BPA), Process change management (PCM) and BPM research projects. Each of these elements is considered a "*Brick*". Each BPM knowledge worker who will have access to this tool is considered a "*Bricker*". Each *Brick* has web 2.0 and web 3.0 functionalities such as blogging and tagging. Every *Bricker* will have their own space known as "My Brick". Figure 2 presents the main interface of the tool presenting all the available BRICKS that are contained in the different web 2.0 functionalities.

This research also included the development of a knowledge management framework to improve collaboration at internal practices in parallel to the SmartBricks development at a testing. An e-survey has been designed and analyzed where a sample of 25 persons from processes and IT in CEMEX have provided inputs that show that besides the SmartBricks tool, incentives, training and a common strategy are also needed before the implementation of such novel tool.

The SmartBricks developed by SUPSI on the basis of the first primitive AWI (application web intelligent—intelligent web application) prototype is a web based architecture organised in three layers: data, logic and presentation. Figure 2

Fig. 7 Knowledge management framework (Flores et al. 2009)

presents the architectural and implementation choices made for the software development: mySQL data base has been chosen for storing all the data, both the semantic and the AWI ones; the Java programming language and Java persistence layer has been used for the business logic of the application and the JDBC driver for connecting to the data base; on the client side, for the presentation to the end user, i.e., the graphical user interface (GUI), the Adobe's Flex technology based on action script has been adopted, providing support for web 2.0 style of interaction.

In particular, the logic layer is the back-end part of the application which manages Java objects within the Tomcat application server. Jena API are integrated as library within it in order to manage the semantic web implementation of data through RDF resources, the ontology editing, and inferences on the semantic world of resources. In the first AWI prototype, all these data are stored in the mySQL database (Jena DBs), providing data persistence, and managing all the domain specific resources about the business process management and its PPRH (process, product, resource and human) classes.

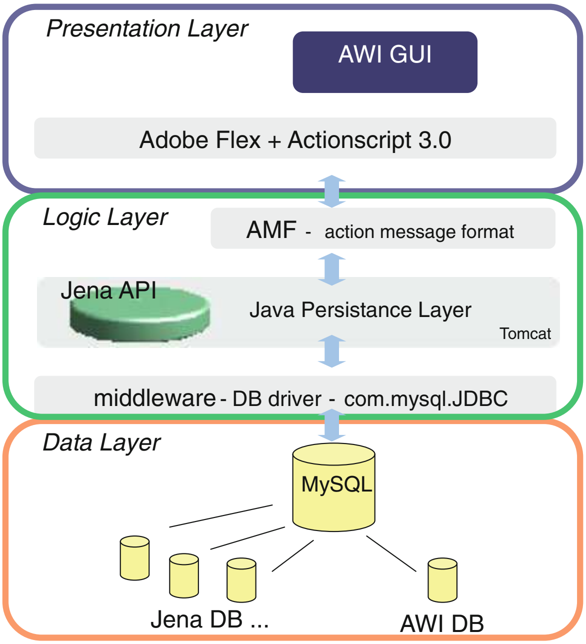


Fig. 8 The AWI three layer architecture and its implementation details

Role in DiFac Solution Development

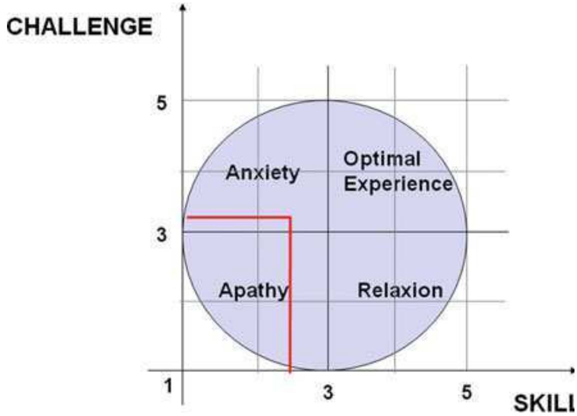
CEMEX research group provided the requirements and specifications for the development of the tool to SUPSI. Once a first prototype was developed, it was then tested with different users from the process department.

Case Assessment

The SmartBricks Web 2.0 platform was tested with about 30 CEMEX employees both in Switzerland and Mexico. A questionnaire was designed integrating some questions from the ergonomics and flow for presence questionnaire (Chaps. 4 and 5). An interregional team composed at the human factors experts, CEMEX reference person and SUPSI developers composed an articulated questionnaire evaluating usability, ergonomics and Presence of the web-based platform.

Unfortunately the testers were ten men working in different positions and with different duty in the enterprise, the number is too low for a comprehensive data analysis, but the ten questionnaires gave us useful information about the actual state of the platform and further improvements.

Fig. 9 Challenge and skill balance



The first section of questions gives general indication about the usage of the system. It results easy to be used not complex to such an extent that testers judge the SmartBrick immediately usable with no experts' help.

Users are satisfied with the functionalities integration, even if some testers deplore some characteristics of the interface that make the navigation among different functionalities non-immediate. Main problem of this beta test version is the very low speed of the connection that blocked an immediate information exchange.

The SmartBrick is a useful "place" where the knowledge is stored and the wiki modality is a positive way for implementing it. The users (four of them) asked to give the possibility to upload information in different formats (i.e., real demo or videos), and not only using written text. The different pages appear too much full with text, even if the design of the different pages is good; the written parts have too much weight. The functionality appreciated is the quick possibility to consult some specific terms by tagging modality.

The third part of the evaluation questionnaire is comprised of a selection of questions by the flare for presence of questionnaire (for more details, please refer to Chap. 4 of this book). The users want to repeat the experience of the Smart-Brick, it has been shown by the general index mean of 4.4. The flow, or the condition of optimal experience during the use of the different sections, has a rate on the border. Actually the skill and challenge balance brings the users' to a state near to anxiety as the image here it showed below. This means that users' skills were not balanced with the perceived challenges of the SmartBrick. The users need more time for training, and this first trial had a precise time schedule immediately followed by the questionnaire. As one of the interviewee wrote: "We need more time to review the tool over a longer period", this will lower the anxiety, making skills higher and the users much more used to the system.

The sense of presence is quite low, but navigating in a web site is not really immersive. Even if the SmartBrick is a 2.0 web site and the users are the actors of the web, they can participate but the intelligent web does not represent the real life, it is a synthetic environment in which people interact via internet clearly.

Strengths	*Weakness*
One to one tool in usage, but knowledge sharing with others	Not sure that SmartBricks can be applied for all the levels and areas of the company. Obstacles can be culture and education of the employees.
	Uploading file not only under.doc format, but also movies or demos
Opportunities	*Threats*
Have a common idea about a term	Overlapping with other platforms already used in the enterprise with similar but partial functionalities

The validation, besides the scarce number of testers, shows the line to be followed for further implementation. First of all higher flexibility of format integration for uploading the files to be shared. The community repository ready to be used by everybody is an important tool for creating a common view and understanding of information. The possibility of easy and fast consultation is a positive point. The different tools in SmartBrick should be much more integrated in the platform.

Obtained (Expected) Results

Overall, the SmartBricks tool showed to different employees in CEMEX the different challenges and opportunities to share knowledge and collaborate within the company. Besides the technical aspect of the tool, it was also identified during the project the need to develop a framework for knowledge management (Fig. 7) that could enable top management to define a strategy and a vision with a clear process, governance and indicators that could facilitate the implementation and cultural change to profit novel digital tools such as SmartBricks. Additionally, an internal team in CEMEX documented an inventory of 70 best practices using a proposed taxonomy. Those practices were documented in CEMEX during the DiFac project and were uploaded to the prototype in order to have available contents for users to test the tool. The proposed taxonomy and the availability of those practices were considered a very useful deliverable within the company.

To conclude, CEMEX has always been a company that believes that Information Technologies are key enablers to gain operational efficiency. Thus, the company, by the time the Swiss DiFac was ending, decided to invest in the deployment of the Connections tool developed by IBM which offers all web 2.0 functionalities. This technology will be implemented world wide in all CEMEX locations and the scope is also to enable an increase in innovation, thanks to the knowledge sharing of employees when collaborating in multidisciplinary projects. The customized version of the tool will be known internally as SHIFT. In summary, the SmartBricks tool developed and tested during the DiFac project enabled the users to get to know and understand in the BPM contexts the web 2.0 functionalities and the different challenges a company needs to take into consideration to become a learning organization.

iPortal and Factory Hub

Ciprian Candea and Gabriela Candea

Company Profile

	Company data
Name	Ropardo SRL
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WWW	www.ropardo.ro
Year of foundation	1994
Number of employees	30
Industry	IT Services
Products	
Markets	

Innovation, Quality and Delivery on Time is our objectives since 1994 when Ropardo S.R.L start as Technology Company based in Sibiu and Romania. Our expertise is in software development, implementation of complex software solutions and maintenance of software/IT systems for world wide customers.

We are specialized in custom software development for different branches/ industries: tourism, automotive, logistic, industrial production (food, plastic), public body, real estate, building/construction and web hosting using different IT technologies.

We provide services in domains like: system and application development, business application, web and e-business/eCommerce, software re-engineering, software test, maintenance and support.

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Ropardo S.R.L provides its customers with a profitable software development source, fast time to market and low operating costs.

Well-defined processes and highly skilled and dedicated team allow us to work with customers from all over the world. Efficient, simple, adaptable and open, Ropardo S.R.L. meet demands and exceed the requirements, overcoming geographical and cultural differences.

Our objective is to provide optimized and innovative solutions, focused on customers' needs. We accomplished this purpose taking into account the evolution of software technologies on the market.

Our company develops and provides software solutions and applications, keeping in mind the real necessities of a successful organization.

Our company, Ropardo S.R.L. works to solve the needs of small, medium and enterprised-sized businesses that work/use software in their activity.

Reasons for Adopting DiFac Solutions

Problem Assessment

Nowadays, business processes change rapidly, especially when a company is involved in making highly customized products or simultaneously running different projects.

This leads to changes in the manufacturing processes and hence to business process reengineering. For these changes to be done after customer requirements a permanent communication is required.

For an enterprise to be successful in such environments, it has to establish a corresponding culture for continuous improvements and be supported by IT responsive business processes.

Another aspect of contemporary manufacturing enterprises is the need for interdisciplinary teams to collaborate frequently with team members who are distributed in different locations i.e., plants, research departments or are external specialist; and because their activities need to be co-ordinated.

When a project team is located at more than one site, it is very difficult to synchronize their tasks and optimize the usage of these distributed resources. Therefore, it is essential that all participants contribute to the creation of the process models in the early stages of the project. In addition, such geographically dispersed teams need a suitable interactive environment to model business processes concurrently. The objective of such collaborative model development is to enable teams to improve their business processes and shorten product lead-times.

A digital factory depicts a hybrid persistent community where a rich virtualized environment, representing a variety of factory activities and processes, will facilitate the sharing of factory resources, manufacturing information and knowledge and help with the simulation of collaborative design, planning, production and management among different participants and departments.

Based on these aspects we consider a factory hub with corresponding functionalities to support project oriented activities on digital factory. Because users are dispersed geographically we consider a web-based solution and taking into account that we like to support SME also we consider an open source solution as technology base.

DiFac Solution

The raised issue is that of process coordination in large distributed business environments. Our solution for this is based on a web software application that supports documents sharing, real-time communication solutions, decision-making processes and other collaborative practices.

Since the users are internal employees, external collaborators-customers and suppliers—a customizable, web-based portal with secure browser access was choosen.

A web-portal or commonly referred to as simply a portal is a web site or service that offers a broad array of resources and services, such as e-mail, forums, search engines and other on-line services. It provides a single point of entry, in the form of a web-based user interface, and is designed to aggregate information through application-specific portlets [Java Community—JSR168]. iPortal may have sophisticated personalization features to provide customized content to users.

Portlets are pluggable user interface components that are managed and displayed in a web portal. Portlets produce fragments of mark-up code that are aggregated into a portal page. Typically, following the desktop metaphor, a portal page is displayed as a collection of non-overlapping portlet windows, where each portlet window displays a portlet. Hence a portlet (or collection of portlets) resembles a web-based application that is hosted in a portal.

iPortal allows registered users to personalize their view of the website by turning on or off portions of the webpage, or by adding or deleting features.

At a closer look through portal features, such as:

- Aggregation of content,
- Customized views,
- Personalized content,
- Collaboration features,
- Web services access,

And so on, we also meet our solution requirements.

i-Portal Technology

To also support SME we choose as portal an open source implementation: Liferay Enterprise Portal (www.liferay.com) which provides a tremendous amount of

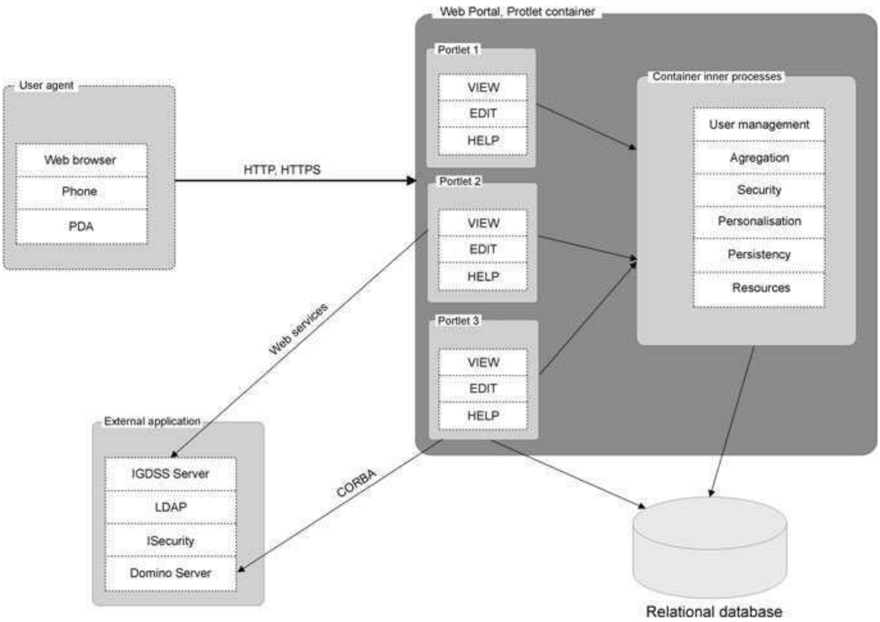

Fig. 10 Schema of the interactions within a portlet container and interaction with the user

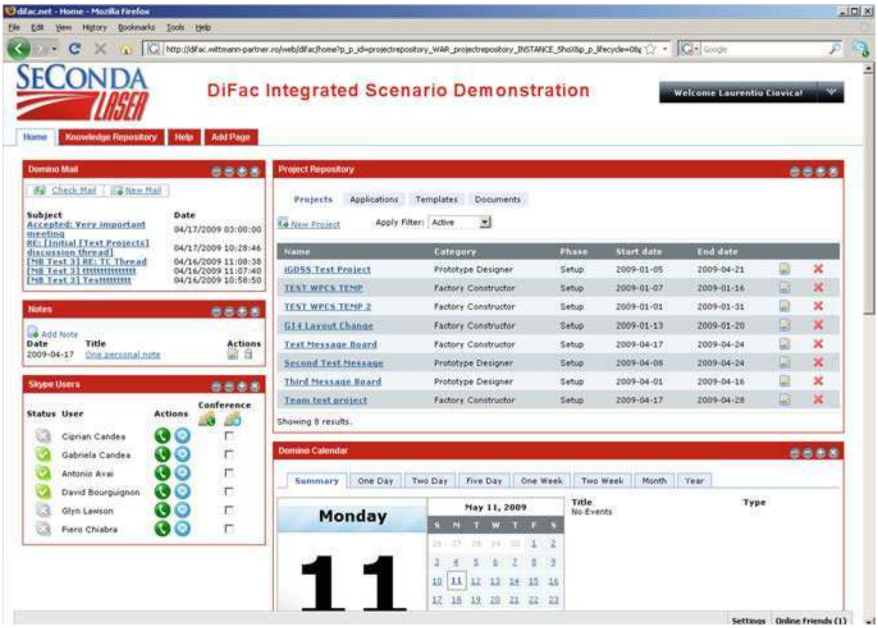

Fig. 11 Homepage for iPortal

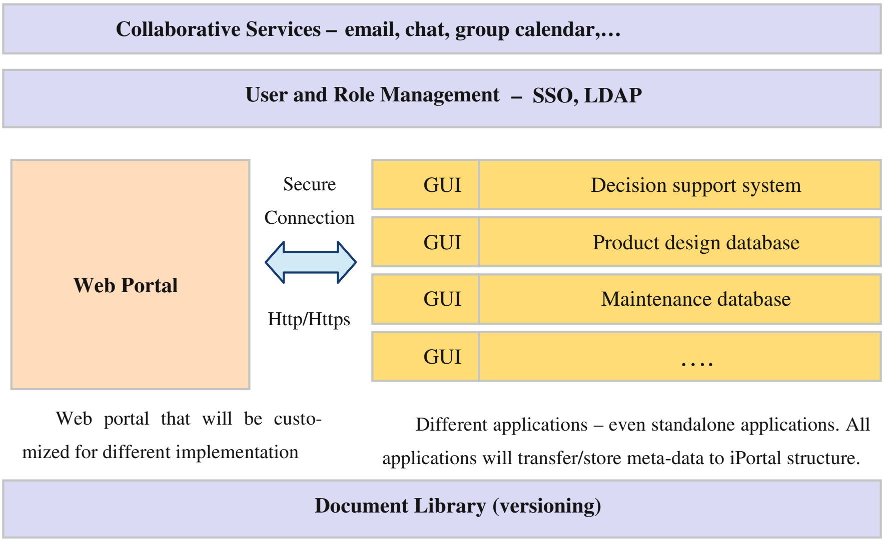

Fig. 12 iPortal architecture

value for very little hassle. It supports a wide variety of J2EE application servers and databases.

iPortal is based as technology on Liferay but it comes with other specific flows that needs to be addressed for Manufacturing environment.

Essentially, to quickly download, set an environment variable, run a shell script, and you have an enterprise portal. It is setup to quickly provide an easily configurable corporate portal, with such nice features as a Mapquest lookup of your company's address, showing an overview map.

Extensive portlets come with it, including search, message board, Wiki, journal, news feeds, weather, calendar, stocks, general RSS, instant messaging, SMS messaging, unit conversion, translator, dictionary and user directory.

The whole framework is built upon Spring, which provides a high likelihood that it would be easy to extend. Being built after the JSR-168 specifications first and for the newest version after JSR-268 other portlets, java-based, are easy to develop and install—at just almost three "click's away" (upload the portlet web application and press the install button and all is done, the portal deploys the application and automatically registers it within the specified category).

iPortal: An Enterprise Collaborative Portal

The architecture of the iPortal considers two issues:

- Allowing stakeholders to collaborate in the context of different activities (project-based tasks)

- Supporting different tools/applications that follow specific targets (VR, factory design, etc.)

In order to efficiently cooperate, stakeholders need a virtual space to access data and to transform it into information and knowledge. The proposed architecture allows integration of any kind of communication tools such as instant messenger, email, while providing a central location to store documents related to different projects.

To enhance specific tools usage for each activity, the proposed architecture aims at integrating different 3rd party solutions resulting in integrated data and processes. Each of these tools runs in its own environment (it is also possible for all the software tools to run in the same environment), while some of them need specific hardware. An extensive range of collaboration features specific for digital factory, including virtual reality, ad hoc tasks, discussion forums, live meetings and interactive polls enables group members to share information asynchronously or in real time. It is possible to integrate the corporate email that makes it easy to track all project related communication, even that taking place outside the collaborative environment.

iPortal presents specific functionalities for collaboration but also one important feature for any company—project-based activity.

The iPortal also features centrally managed, role-based security. Administrators control security for members of the enterprise and their group assignments. They can only configure roles and assign users to them, and will not be able to override security policy on an individual level.

iPortal can integrate applications like enterprise email server (i.e., Domino, Exchange) and successfully integrate emails, chat, calendar and tasks; it allows different components to send/verify data (agenda, emails) related to a specific user and project; the actions to be performed refer to assigning emails to a project, or saving chats into the projects section.

User and Role Management provides identity management, multi-layered and object security to ensure that only users authorized to access sensitive business information are provided access. Standard-based authentication with industry leading LDAP directory servers and single sign on (SSO) providers—this means user and group information is managed and maintained within the corporate security infrastructure. This feature is designed in a way to allow integration with other corporate solutions in case those are already implemented (i.e., Active directory, Open LDAP etc.). This component is designed to manage the roles of each user for each application—with this an integrated and centralized place to manage rights is being achieved.

Web Portal is a virtual location with a dashboard-like interface integrating all modules and therefore offering the user a central information point. From here the user can log-in and access information depending on his/her given access rights. iPortal database stores only filtered data from each integrated application. For example, in case of decisional support system, the user will see for each project: the data posted by team members for a specific thread (comments, new input);

deadlines and inputs required etc.; all this information belongs to the decisional support application, but through the portlets technology it can be accessed from iPortal dashboard. At the iPortal level project related actions are defined and managed via User and Role management component.

Third party applications will communicate with iPortal to fetch specific information relating to projects, while all complex behavior including specific GUI runs at application level (i.e., CAD solutions). Some information—job summary, to do actions, etc. are communicated to iPortal and pushed to the end user.

The concept of "project-based" activities is being introduced, focusing collaboration around projects. This enhances managing data and capturing knowledge on specific topics, and also determines a better organization of tasks and solutions. Project content stored in the repository can be easily referenced and accessed from the existing applications. There is no need to create duplicates of the documents or go through additional authentication procedures. Tasks in the iPortal environment can be part of defined enterprise workflows, where the workflow stops until the collaborative work inside the project is completed at a point which it automatically continues processing.

Each project is spread in iPortal in the sense that each project has its own wiki space, its own main folder in the document library and the information about each project is also propagated to each 3rd party tool (iDSS, prototype designer etc.). This way, project data can be easily grouped and structured.

Projects are created based upon *templates* which can also be managed in iPortal by the users. There are by default a set of templates for each implementation/ customer (i.e., Factory Constructor, Prototype Designer and Training Simulator) and, besides these, custom templates can be created based upon certain needs.

The *Project wiki space* is generated upon the project template and it contains all the initial information about the project (workflows, tool links, general information etc.). From this wiki space, the *document library folder* can be opened to manage the project related files.

iPortal: Services

Agenda Planning

In any form of collaborative work, agenda planning is a key feature. iPortal provides an inner calendar for planning different events (meetings, reminders, appointments, etc.) which is accessible through the *Calendar portlet.* This portlet displays a summary of events that take place in the current day and also can display a detailed list of events for the current day, (for two days, five days etc.).

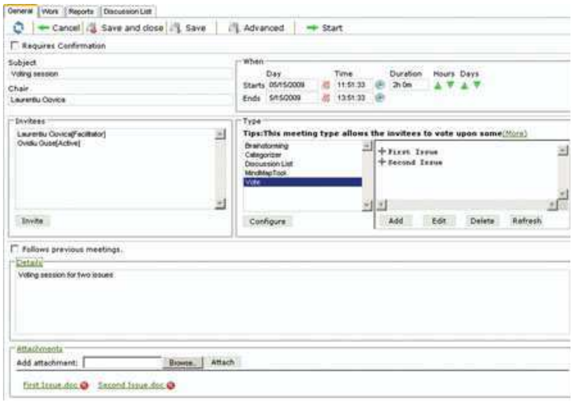

Fig. 13 Voting session

Fig. 14 Skype portlet

Decision Support

In order for the iPortal to support decision support functionalities, it is used an existing Ropardo, called *iDecisionSupport System* (iDSS). This is designed to be a collaborative decision-making support system with safety, utility, efficiency, effectiveness and usability. The development of iDecisionSupport is based on the principles of DSS (Decision Support Systems), interactive software and related development techniques. By taking advantage of abundant information on the Internet, networking and database technologies, iDSS provides decision-makers: comprehensive information access to internal and external data, communication facility and friendly interface with multiple-user access.

The iDSS component provides intelligent workflow and decisional support customized for specific DiFac needs, enhancing organizational memory; decision-making tools (brainstorming, voting, categorize etc.) integrated within iPortal and customized for Manufacturing flows. Advantage of using integrated decisional support tools in iPortal consists of better quality group decision for their tactical and operational activity. Also, iDSS is developed as a conceptual tool where any third party can contribute with creative ideas for modeling the decision-making processes—“third party” tools.

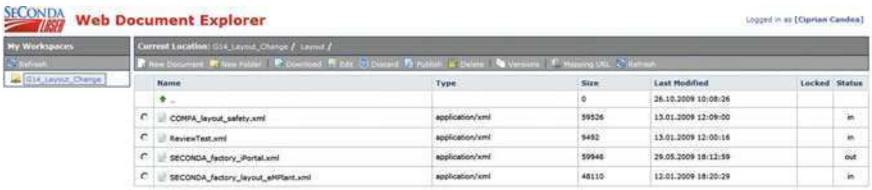

Fig. 15 Web document explorer

iDecisionSupport is made up of few initial tools aiming to assist the user in the decision-making process:

- Electronic brainstorming is an idea–generating tool that allows participants to share ideas simultaneously and/or anonymously on a specific question(s) posed to the group.
- Categorizer assists groups in three common group activities: generating lists of ideas, brainstorming comments that elaborate on or support the ideas, and creating categories for the ideas.
- Topic commenter (discussion list) helps groups comment on a list of topics. Participants can also be given the ability to add topics.
- Vote is an evaluation tool capable of providing the basis for a group decision. This tool is also commonly used to determine the degree of group consensus.
- MindMap tool—used for action plans and brainstorming.

Collaboration Work (e-mail, Message-Board, Skype)

iPortal contains a suite of collaboration support tools in the form of portlets. Among these the most important are Mail, Calendar and Skype.

Mail is a small portlet that displays a short preview of your e-mail inbox. The user can open his/her mailbox from this portlet and also start composing a new mail.

Calendar displays a summary of the events in the form of user's personal calendar.

Skype is a web-based Skype "clone" which provides features such as: skype-to-skype calls, conferences, user profile or user status. (The user status can be seen only if the user allows this by checking the *Allow my online status to be shown on the web* option in the Privacy Settings of Skype).

Document Explorer

This component is a document library that provides users with centralized file storage and retrieval access with check-in/check-out functions as well as

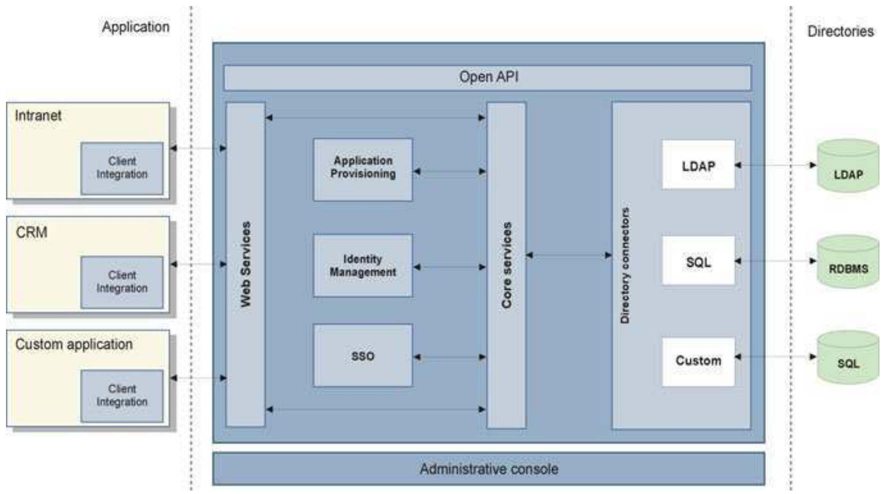

Fig. 16 User management architecture

possibility to add Meta information tags. With this users can work on same versions of files improving cooperation and quality info into projects. Knowledge database creates organization memory that can be accessed/reused for new projects/decisions as experiences. This document library can be accessed using the document explorer application and through the Web DAV internet protocol.

The procedure of editing a file can be done in two ways that have a common starting step. First of all a file must be locked for edit by clicking on the *Edit* button in the menu. Then, the file can be downloaded, edited locally and then published, this way generating the new version. The second way is to leave the file in the server (lock it but do not download it) and use the WebDAV mapping URL to edit and save it directly in the document repository with the specific editor. Of course in this case, the editor must support these WebDAV operations and there is also a library for implementing them if desired.

Identity Management

The iSecurity (solution for Identity Management) is focussing in delivering a central platform and security services to managed applications. It can be seen as a buffer between the client applications and their specific backend data-store. The system is not only supposed to integrate applications which already have such a backend data-store available, but also new applications seeking to integrate security features in their implementation. Exposed and supported operations are described as follow:

- *Application provisioning* capable of interacting with the customer's applications providing a single common communication interface, while in the backend will be able to integrate different directories like LDAP, relational databases, etc. (here "directory" represents a generic term describing different types of data storage solutions).
- *Identity management* that provides a centralized identity management module allowing the administrators to take users from different directories and manage them in one place. Multiple user directories can be plugged transparently under the same umbrella and conveniently managed via a unique management console.
- *Single Sign-on* with the ability of querying different directories (with different physical implementations—e.g. LDAP or database oriented, etc.), the system will be able to consolidate the user authentication through all provisioned applications and use a single, common security interface for it.

Through web-services all the provided services are made available, so that it allows different client implementations to be accepted. So the iSecurity server can very well communicate with a.Net, PHP or Java clients—feature that gives great development flexibility.

Having the iSecurity framework developed the iPortal and additional by developed portlets/applications are fully integrated with it creating a mature and enterprise collaborative solution for customers, suppliers and employees.

Knowledge Management

Knowledge management is a pure and abstract utilization of information with a touch of wisdom in a collaborative space. Knowledge is the object that can be manipulated, identified, associated and handled in information systems. Knowledge is not information, the latter is a single part of knowledge, focused on describing, defining an entity.

The management perspective is the practical view of an organized collection of knowledge. A statement of business has its own definition by using knowledge management. Dismissing what is redundant and overcrowded in terms of management process from a business, creates an effective motor that charges from its own mechanism. In a knowledge management, information is the key, and knowledge is the tool with which we create strategies, methods of usage for existing data and approaches to current issues.

Into iPortal we introduce wiki techniques to address knowledge aspects. Using wiki users are collaborating and transferring knowledge and they have access to all the information that is available with the relationships between them.

A defining characteristic of wiki technology is the ease with which pages can be created and updated. Generally, there is no review before modifications are accepted. The *wiki* of iPortal is a component that supports project content generation and project templates generation. Using this component any user can create documents where he can share his experience and expertise with the new members of the community or just exchange ideas with professionals who are part of the entire virtual environment.

The wiki includes a number of professional features:

- User rights management (by wiki/space/page, using groups, etc.)
- PDF export
- Full-text search
- Version control
- Content and site design export and import
- Plugins, API, programming...

Future Perspectives

The iPortal concept and technology has reduced the time and expense of new product development as well as provided the ability to have 24×7 communications with customers on new product features and status. Being an enterprise solution and integrated with iSecurity the portal also provides highly secure environment so confidentiality and privacy can be maintained.

The goal for this project, therefore, was to find and deliver as much information as possible to those who needed to make the daily decisions that are part of running any business. Using wiki any user can create documents where that can share experience and expertise with the new members of the community or just exchange ideas with professionals who are part of the entire virtual environment. An entire businesses process can be included in wiki, the latter making the experience of designing, creating a product, brainstorming with your group or other group members, testing and learn into from professional experience.

iPortal had to provide the information in a collaborative environment that would provide real-time customer, supplier or employee metrics and other information to desk tops, laptops and PDA’s, so decisions could be made with the greatest amount of knowledge and wisdom.

Through iPortal both the manufacturer and their customers now have better visibility into what and how their businesses are doing.

Service and Remote Maintenance

Pietro Pittaro

Company Profile

	Company data
Name	Prima Industrie S.p.A.
Address	Via Antonelli 32 10097 Collegno (TO) ITALY
WWW	http://www.primaindustrie.com
Year of foundation	1977
Number of employees	1,700 in 40 countries
Industry	Machine tools
Products	Laser cutting robot and machinery for metal sheet working.
Markets	All over the world for Metal sheet processing, electronics, automotive, aerospace and energy and others

Prima Industrie S.p.A. is one of the worlds major companies currently operational in the development, manufacturing and marketing of robotic laser cutting equipment.

The Prima Industrie group has the headquarters in Collegno, near Turin with about 300 employers. It designs produces and sells worldwide laser cutting and welding robot for 2D or 3D applications.

Prima Electronic, located in Moncalieri and Barone Canavese, near Turin, is the company that designs and produces the electronic and software parts, CNC numerical control, motor servo-amplifier and laser control unit not only for the Prima group but also for the market.

Convergent laser located in United States of America produces the laser source for our systems.

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L. Canetta et al. (eds.), *Digital Factory for Human-oriented Production Systems*,
DOI: 10.1007/978-1-84996-172-1, © Springer-Verlag London Limited 2011

Prima laserdyne produces specific laser system for drilling.

Some joint ventures in China produce laser system for domestic market.

Last year Prima Industrie bought FINN-POWER, a Finnish company worldwide leader in machinery for metal sheet working.

The Prima Industrie—Finn Power group have about 1,700 employers in 40 countries.

Reasons for Adopting DiFac Solutions

The DiFac innovative tool offers a complete and integrated solution for the SME machinary manufacturing Industries like Prima Industrie S.p.A.

Many components of the DiFac project can be useful for Prima Industrie S.p.A. starting from prototyping design, portal solution, virtual factory planning but we start focussing our effort on the training simulator and remote maintenance tool from Metaio Gmbh. The three DiFac pillars components: presence, collaboration and ergonomics are the new approach at the manufacturing process using digital tools.

Problem Assessment

Prima Industrie S.p.A. designs, manufactures and markets high technology systems with more research centers, factories and service offices in different countries. With more than 2,300 installed systems and a high rate of new products Prima Industrie S.p.A. also need new and innovative tools to manage the know-how and communication flow.

Objectives

Using the DiFac–Metaio Gmbh solution for service and remote maintenance, we offer our customers a quicker, cheaper and better answer for technical problems that are caused by our systems.

DiFac Solution

Metaio Gmbh tool-based on augmented reality technology is the easiest solution to create and use the procedures having all the advantages of the real world images superimposed with virtual information to guide effectively the technician on site.

Fig. 17 Starting image on the lens cleaning procedure

Role in DiFac Solution Development

Prima Industrie S.p.A. is an end user in the DiFac project and in this rule shows the real information and steps sequence to create a service and maintenance procedure for industrial machinery systems. The customer service experience of our technicians allowed to define all the information the tool needed to guide the procedure execution and how to call easily a skilled remote technician to interact with voice and video on IP using integrated auxiliary tools. The skilled operator can also modify directly the procedure if necessary and download it immediately on the portal server.

Internal the Enterprise

The first augmented reality (AR) procedure was made with Metaio guide that explained to Prima Industrie technicians how to use the package. This first "Lens cleaning procedure for Platino system" started from the the standard "static" procedure we already have in our manual to translate into Metaio workflow using the authoring tool. Otherwise Metaio package was customized for Prima Industrie to show and work with all the maintenance information the worker on site need for this typical operation. After the first test-guide procedure our service technicians started to choose and create new maintenance procedures to use for our Platino laser cutting robot system. The new AR procedures created showed a better communication worker on site—skilled technician if some questions occur during the procedure. Watching the system and speaking directly during the procedure helps strongly our skilled technician to understand better and immediately the problem on the machine site. Executing the new procedure we also verified some problems relating to the image tracking in workshop environment. Some limits are present with reference or small parts and not good lightness also related at not easy positioning of the camera on the machine system. Increasing our experience in the video camera use I think we can solve most of these problem related to the image acquisition.

Externally on the Market

Using the AR procedure for remote service and maintenance we verified the possibility to solve quickly the problems of the customer with great satisfaction. We also verified the costs reduction we can have directly related at the communication we execute now completely through IP other than the cost related at the time and travel than greater cost related to the web camera the cost we need for the AR procedure is small; less than 100 € for a good quality device. Consider that having a web camera on the system is in any case a good opportunity for a better and immediate communication between worker on site and skilled technician also out of the AR procedure.

Obtained (Expected) Results

The result obtained after starting to use the AR procedure for service and remote maintenance seems encouraging. By using the AR procedure for remote service and maintenance for the most common and critical procedure we think to reduce the machine stop time and overall cost. AR technology is a new methodology for our procedures but it is good to start using this approach as we think this will have more and more development in the future.

Factory Emergency Training Using Constructive Workplace Simulation

David Bourguignon

Company Profile

	Company data
Name	MASA group
Address	8 rue de la Michodière
WWW	http://www.masagroup.net/
Year of foundation	1996
Number of employees	45
Industry	Software publisher
Products	Sword, life
Markets	Simulation, defense, security

MASA Group is a leading provider of advanced software solutions using Artificial Intelligence technologies for modeling and simulation. The group operates out of Paris (France), Norfolk (Virginia, USA) and Singapore. For more information, visit http://www.masagroup.net/.

Reasons for Adopting DiFac Solutions

Problem Assessment

Emergency training in factories is currently very rudimentary. In most cases, safety managers re-issue each year a disaster mitigation plan to comply with current

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legislation. This plan contains a possible strategy that experts consider as the optimal solution to the problem. This assertion is often fragile: this was unfortunately demonstrated by many large-scale industrial disasters that occurred in the past twenty years. Real-life exercises are time and human resource consuming and they remain limited also for practical reasons. With this scenario training is more than ever necessary for safety managers practicing less and less real incidents due to the increasing quality of risk prevention. Procedures, techniques and situation assessment skills must be easily and repetitively tested without endangering trainees, and without the need for expensive real size training infrastructures.

Virtual reality simulations are now widely used for training in safety emergency applications. Some examples of possible emergency reaction training applications are: training airport crews in handling airline crashes (Weiss and Jessel 1996); training in first aid procedures (Kizakevich et al. 2006) and training of fire-fighters (Stone 2001) among others.

Behavior simulation study is particularly interesting for this sector. Actually, simulations are directly amenable to automation by using autonomous agents to populate training environments and increasing the realism. MASA developed its DirectIA decisional AI engine to create autonomous agents capable of adapting to situations that are not programmed or predicted. This characteristic is extremely important in many occasions: it permits to stimulate decision-makers in several situations as in military command posts, crisis response and incident management teams to train and prepare for unplanned situations. In fact, virtual environment enhanced with human behavior simulation offer an increase in training efficiency as this allows the incorporation of human factors, thus creating more complex training situations. Behavioral simulation also results in a reduction in training costs as it reduces the number of training personnel required for the exercise by taking in charge part of the burden of animating the simulation.

Objectives

Planning emergency situations and have correctly trained employees at dealing with them is a critical success factor in SMEs, which often have limited financial and human capabilities to recover from such events. Real training and emergency exercises are expensive in time and resources. The idea raised by the project is to provide tools to make emergency planning and exercising a day-to-day practice in European SMEs.

DiFac Solution

The functional architecture of the Factory Emergency Training Simulator distinguishes among several training types, depending on the kind of virtual environment used. In the military sector, training simulations are usually classified in three levels: either live, virtual, or constructive.[1] In each of these categories, the degree of human participation in the simulation is variable, as is the degree of equipment realism.

The Training Simulator provides four functional steps, which are:

1. *Select the purpose of training*: The domain expert chooses the topic of the training, either on their own, or together with the trainee. Several factors may have contributed to this, for example, training needs analysis, succession planning or company training initiatives.
2. *Setup the procedure*: The domain expert sets up the training (downloads relevant files, opens relevant software applications) before inviting the trainee to join.
3. *Execute training*: The training can take several forms (for example virtual or constructive simulation as described above) although common to all of these is an exchange of information between the domain expert and the trainee. This could be done either directly, in a question and answer session, or indirectly, when the trainee issues orders which are implemented into the training simulation by the domain expert. Alternatively, in a self-train situation the domain expert's knowledge is already captured in the training system, and the trainee can learn through experimentation and practice, asynchronously to the domain expert's input.
4. *Review and evaluation*: The trainee should review their performance (possibly with the domain expert, or alone if self-training) to identify whether they have learnt satisfactorily the skills identified in Step 1. Automated performance indicators can support this review. Furthermore, the domain expert and/or the trainee can evaluate the training material, with a view of improving the efficiency and effectiveness of the training. The results of this would feed back into step 2.

Figure 18 shows the emergency training full component architecture. The training system is typical client–server architecture, composed of two sides: on one hand a simulation server, and on the other hand, two types of clients (for trainer and trainee). They provide visualisation and general services for interacting with the simulation. Several databases are read/written by both the server and its clients.

In Fig. 2 the hardware architecture shows the physical components required for the training simulator, and the relationships among them.

---

[1] Training simulations are usually classified in three categories: either live, virtual, or constructive (US DoD, 1995). The commonly accepted definitions are:

- Live simulation: a simulation involving real people operating real systems.
- Virtual simulation: a simulation involving real people operating simulated systems. Virtual simulations inject human-in-the-loop in a central role by exercising motor control skills, decision skills, or communication skills.
- Constructive simulation: a simulation involving simulated people operating simulated systems. Real people stimulate (make inputs to) such simulations, and in turn are stimulated (receive outputs) by them, but are not directly involved in determining the outcomes.

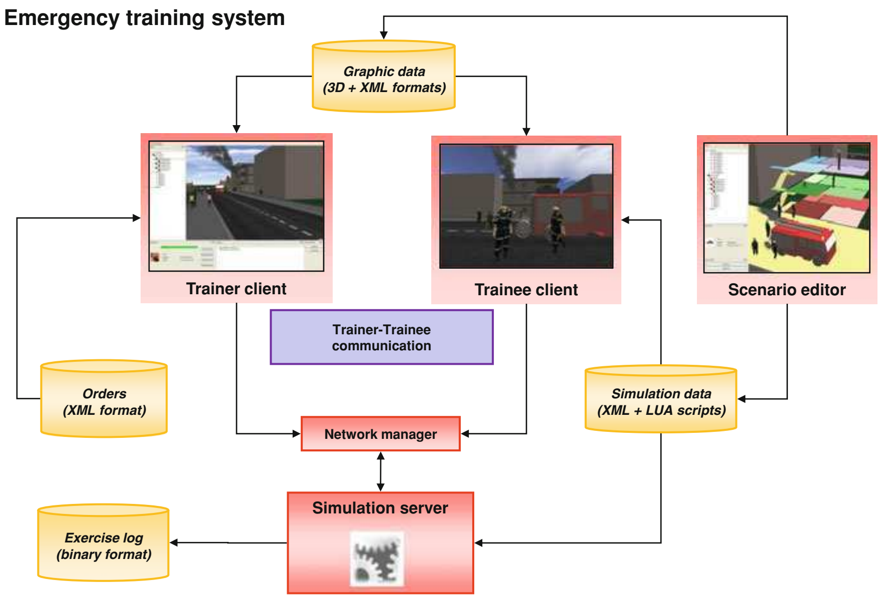

Fig. 18 Emergency training system component architecture

In the self-training mode, students have the same view as in the trainee (see Fig. 4), but they can give themselves using the same interface as the instructor mode (see Fig. 3).

By opening the after-action review tool, one can choose which training session to replay among the list of available past training session records. Once a session has been chosen, a 3D window opens, similar to the instructor window, with a time slider which allows controlling the replay. This time slider allows the instructor to move the time forward and backward. The start exercise/pause exercise button allows the user to start/stop replaying the training record, from any moment in time.

Role in DiFac Solution Development

MASA Group, partner in DiFac, has entirely developed and tested the Factory Emergency Training Simulator, on behalf of the DiFac consortium.

Case Assessment

General training market: The training market in Europe has undergone recently important changes with the advent of e-learning, which has allowed software-

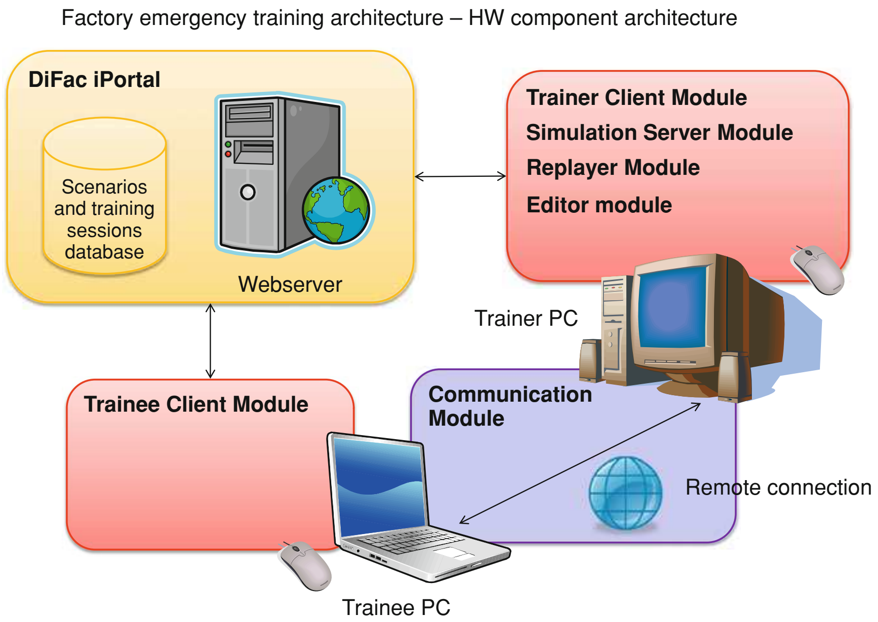

Fig. 19 Emergency training hardware architecture

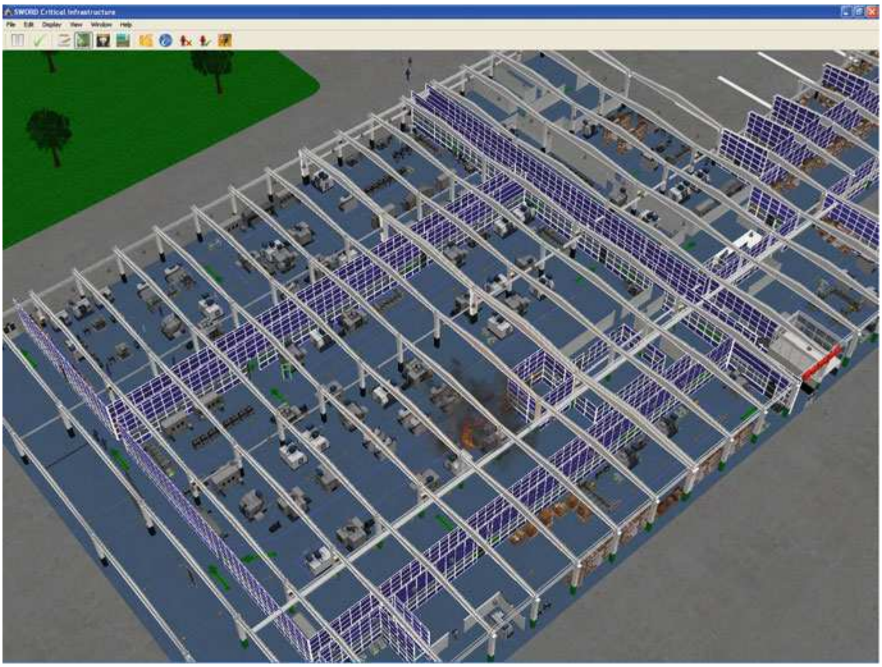

Fig. 20 Instructor mode (bird's view). The instructor mode has several parts: a menu, a tool bar, and a 3D view

Fig. 21 Trainee mode (immersive view). The student is immersed in the 3D scene through the subjective view of the trained worker

based training to become nearly as important as the more traditional presential training (Price Waterhouse Coopers 2004). However, MASA simulation-based training, either virtual or constructive, could be considered in fact as in-between e-learning and traditional presential training.

MASA develops simulation-based training solutions allowing those who make decisions in a crisis or operation to see the potential effects of those decisions in exercises. These tools allow experimenting with new concepts, courses of actions, or systems to help commanders or managers in the field. The success of these training simulations comes from the fact that they require less human or material resources than traditional training.

More precisely, all MASA technological modules can be either (i) embedded as components to enhance existing simulations or (ii) interconnected with a geographical information system (GIS) to populate a synthetic terrain. Three kinds of application areas can be targeted:

- Preparedness: to immerse groups or individuals in realistic situations in order to improve their skills and experience.
- Serious gaming: to study and improve operations concepts, courses of actions, techniques and procedures.
- Technical lab: to stimulate operational systems in order to simulate environment and effects for system development and future decision support.

Factory emergency training with virtual simulations: These virtual simulations are aimed at primary intervention teams. They are immersive, game-like application for factory safety training and decision support. They immerse the primary intervention team group leader in a simulated environment to test its decisional skills, and rehearse intervention procedures.

Since most emergency teams in factories are firemen, a specific tool for training firemen group leader could be of particular interest within DiFac, by allowing the conception, test and optimization of emergency plans and procedures, with respect to the specifics of each site.

Factory emergency training with constructive simulations: These constructive simulations are aimed at civil security command posts and incident management teams who want to train and experiment. Beyond providing training capabilities, the system could be used to validate interagency emergency and crisis management plans, and/or drill a specific structure (fire rescue services, energy providers, water distribution and health services) while simulating the others.

While more and more crisis management structures become equipped with digitized information management systems, these constructive simulations provide for them a way to train, rehearse on experiment on the real terrain of operations.

Future Perspectives (Future Applications of the Tool, Future Development)

Innovation can be found in MASA behavior model technology used for complex behavior modeling within the training simulator. Behavior models allow embedding autonomous entities displaying complex behaviors into any kind of computer simulation or serious game. Their main benefits are:

- Providing simulated entities with more realistic behaviors (i.e., displaying autonomous behaviors and/or following given operational doctrine).
- Decreasing cost and improving performance of existing systems (entities do not need to be fully supervised by a human operator).
- Allowing users to be closer to their operational work (i.e., entities understand operational level orders, rather than raw simulation ones).
- Allowing simulation providers and end-users to create any kind of entities based on provided behaviors, easily modified to exactly fit their use.
- Behavior Models provide data and tools gathered into Behavior Libraries, together with tools and interfaces to easily integrate behaviors into any kind of application.

Finally, innovation is provided through the use of autonomous agents displaying realistic behavior in virtual environments for improving presence. Currently, virtual environments contain only human players (such as in Second Life™) or are populated with autonomous agents displaying unrealistic behaviors (such as in World of Warcraft^{TM}). Thanks to situated AI technology, it is now possible to add to virtual environments a new type of agents that are both robust and exhibit a rich set of behavioural patterns, including typical human mechanisms, such as compromise.

Integrated Scenario

Claudia Redaelli

Company Profile

	Company data
Name	Seconda
Address	–
WWW	–
Year of foundation	–
Number of employees	–
Industry	
Products	
Markets	

Seconda is not a real company. The Integrated scenario presented here is a hypothetical but real-possible industrial case in which all results from European DiFac project are applied in a unique company making passing from a digital to a virtual factory. Seconda Laser Machine Company builds laser machines on demand. They can provide 2D and 3D laser machines following requirements from clients.

Reasons for Adopting DiFac Solutions

Problem Assessment

Seconda Company has different departments delocalized in different places in Europe. The General manger, the different engineers and designers work in

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different places but they have to meet together for taking decisions. For saving time and money they want a virtual, collaborative tool to work together remaining in their respective offices. The problem is not only to have a meeting, which is already solved by video calls, but also to work in real time staying in different places. So the engineers can collaborate with designers for designing new products, the general manager can use a decision-making instrument with all her collaborators to reach the better decision, finally engineers can collaborate together with ergonomics experts and training people for having an effective and safe environment to produce a new product.

Seconda's general manager decides to go to her office today. Usually she can carry out much of her work from home, which means that she is able to live where she has always wanted and not have to deal with traveling everyday on congested roads. But her office is equipped with the latest projection technologies and various virtual reality and augmented reality devices and she needs new technologies today.

DiFac Solution

Seconda's general manager has to organize with her colleagues the design and production of new customized Platino laser cutting machine for one of their client: PACOM.

The realization of this product implies some phases done in a collaborative way among people physically located in different places in Europe. Using DiFac iPortal (already presented in a previous case study) for designing the machine components, evaluating them and presenting the cell to the PACOM customer, the entire process results easier and faster. The new project generates consequent changes at the shop floor, through the iPortal the factory planner and the general manager can re-plan the production line and evaluate it on ergonomics and emergency level.

Finally the augmented reality technology allowed the customer to have a remote maintenance service through the DiFac iPortal.

The general manager uses the DiFac solution to launch the new project.

First she logs-on to the iPortal to review her dash board. She needs to schedule a meeting with the designer, assembly engineer, maintenance engineer, factory manager and safety manager.

By using the on-line calendar, the general manager chooses an appropriate date for the meeting. She invites the designer, assembly engineer, maintenance engineer, factory manager and safety manager to participate.

At eleven o'clock, she hears virtual knocks signal that other members of the development team are arriving for the meeting in a shared collaborative virtual space. The GM explains the project and asks the team to use the DiFac solution to:

Design a customized Platino cutting laser machine

Design the laser cutting cell

Re-plan some parts of the actual shop floor

Organizing the meeting in a virtual space enables the use of many sources of information to support it, for example documents, videos, the internet and 3D models.

The designer and the factory planner are working on the same project. After authenticating in the iPortal they create a new design project through the prototype designer's link.

Both designers can see each other's modifications.

After the session with the designer the factory planner understands that they need a new shop floor layout. The factory manager accesses the iPortal and downloads the layout of the present shop floor. He starts the GIOVE Virtual Factory and he imports the downloaded layout. After a sequence of operations that makes the environment exactly as he wants like as move/rotate, duplicate machines, add trolleys and workers include some machines and workers into the process and link them together, he saves the layout into a new project and uploads the new layout using the iPortal.

The new factory layout is going to be reviewed by the factory manager and a blue collar worker in a collaborative way. The blue collar checks the ergonomics aspect of the workstations and he optimizes them. The new layout is now ready to be simulated with a web-based user interface.

The simulation expert, in a collaborative session with the factory manager, adjusts the parameters of the resources. The simulation run returns with the aggregated statistical results evaluated.

At the end of this session the factory manager contacts the security manager for preparing a training session checking the emergency constrains of new organization.

In the meantime the project of the new Platino manichine is completed and the general manager reviews it evaluating the final design and assembly options.

She calls the designer; both access the prototype designer and share the same file. The designer explains that there are two different options for the design of a specific part. She can see any changes he makes and she also can make changes too. The general manager cannot decide between the two options as they both have advantages and disadvantages.

She asks the designer to set up a voting session. Different subjects like the factory manager, the assembly engineer, the designers and the general manager are called to evaluate the importance of some instructions.

SECONDA's assembly engineer shows to the PACOM's representative the new laser machine. During the session, the assembly engineer demonstrates to the customer the different options, the physical constraints and the set safety rules.

The customer is now joining the collaborative session with the assembly engineer, who shows customized Platino laser cell configuration and to the lens box. The customer asks for some modifications in the head.

After the customer is satisfied, the production of the new machine is started with the new designed production layout. Now the security manager needs to organize a training session for checking the safety procedures with the proposed layout. This appears as more realistic training experience with no physical danger, or costly interruptions in the production line.

The Platino machine has been sold and during the last 3 months it worked at PACOM site. But one day it stoped due to unknown reasons.

The worker on site needs to perform a maintenance task at a Platino laser machine of SeConda Company. He can perform the maintenance task by himself supported by Augmented Reality technology. He starts the SeConda remote maintenance application, points the camera at the Platino machine and loads the maintenance procedure workflow. The augmented reality view of the application shows him the necessary tasks in an intuitive 3D way accompanied by textual information. During execution the worker encounters a problem and needs to ask for an expert's help. That way she can quickly understand the problem.

The maintenance manager then decides to update the procedure to avoid such a problem in the future.

Case Assessment

When analyzing the strengths, weaknesses, opportunities and risks of the Seconda Company, it should be emphasized that the Integrated Scenario is a theoretical example. It was created in order to test the feasibility and practicability of

Strengths	*Weaknesses*
Innovativeness of solutions for SMEs using new technologies Organisation flexibility, production efficiency, and a good attitude towards innovation Collaboration in real time from different places, saving time and money A link among different locations helps to promote team spirit, motivation and communication. Even though the people are distantly located they still feel present and part of a virtual office. Being a theoretical case all project results are clearly presented and their use underlines advantages	Lack of real industrial application for the entire DiFac toolset New technologies to be customized for specific industrial needs The new solutions can be added to pre-existent technologies, but an expert must fix the set and train the people from the SME.
Opportunities	*Threats*
New technologies adoption. Answer to SMEs needs by applying VR tools and collaborative instruments EU-funded project has given the opportunity to create a concrete set of tools, moreover, a network of contacts and relationships with a wide range of entities. Technological evolvements can be applied and tested within a theoretical test that is mirror of a real one.	Industrial requirements identification for customization of the results. Persistence of results passing from prototyping to real manufacturing production.

innovative new technologies. The main purpose of the integrated scenario is to present some possible applications of the DiFac EU results to the manufacturing sector.

The SWOT analysis provided in the table below attempts to take into account industrial partner's suggestions and the ideas from the external SME group who participated to the validation phase of the project.

One of the major strengths also lies here: the innovativeness of the adopted technologies and the offering of an integrated toolset for co-design product and factory, training people, simulating production and decision-making that meet the needs of companies with different geographical locations.

Future Perspectives

Since this case study is theoretical, there are no specific future perspectives for this. Foreseen action at the end of the project is the exploitation of the results. The toolset will be customized entirely to be suitable for other manufacturers.

A Korean Automotive Case

Y. Rim

Company Profile

	Company data
Name	An automotive company
Address	–
WWW	–
Year of foundation	–
Number of employees	–
Industry	–
Products	–
Markets	–

This case study deals with an automotive target company which produces different vehicles for the world-wide market. There are a lot of workers for manufacturing products on the shop floor.

Reasons for Adopting DiFac Solutions

Problem Assessment

To produce a car, a lot of information and processes are required. These data are managed by various computational systems. They are sometimes changed to

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DOI: 10.1007/978-1-84996-172-1,

different format or contents with the several processes from whole car product lifecycle. In general, concerning manufacturing aspects of product, most important information in the entire car production lifecycle can be specified with *PPRH* (product, process, resource and human) information. In particular, human information is essential in terms of ergonomic analysis. So far, most engineering researches are just focused on product, process, and resources information. But, nowadays, workers management is becoming a common issue. Ergonomic analysis such as risk analysis with usage of tools, lifting works and assembly works are very important tasks. PPRH information can be used by heterogeneous applications and systems. But the reason for different data structure is that there should be a defined-rule or methodology for defining the aspects of data exchange among heterogeneous applications. Basically, PPRH information is managed by PDM (product data management) systems. Based on the information in PDM systems, the engineering tasks as planning, designing, process planning, ergonomic analysis, simulation, material handling and system design can be performed with their specific application in distributed environment. Because of these backgrounds, an integrated management of PPRH information and framework for collaboration is essential. A web-based framework for collaboration in distributed environment and integrated schema of PPRH for the interoperability among heterogeneous systems is required to maximize the profit

List of jobs for the door installation process (Scanned table from Rim et al. 2008)

Line	Process	Operation	Unit work
Trim line	23rd process front door install trim line	Remove the front door from a hanger and then fit to the car body	Grip the door using a manipulator
			Remove the door from a door hanger
			Fit the door to the body
		Match the front door	Match the door to the car body using a manipulator
		Check the front door and assemble with the car body	Check holes on the door and the car body
			Assemble two bolts
			Adjust torque using a torque wrench
	24th process rear dorr install trim line	Remove the rear door from a hanger and then fit to the car body	Grip the door using a manipulator
			Remove the door from a door hanger
			Fit the door to the body
		Match the rear door	Match the door to the car body using a manipulator
		Check the rear door and assemble with the car body	Check holes on the door and the car body
			Assemble two bolts
			Adjust torque using a torque wrench

and flexibility and to minimize the cost, time and delivery date.

As previously mentioned, there are many manual assembly operations in the automotive general assembly. Especially, the door installation process presents the majority of worker's exaggerative joint movements in the human upperbody. Because of these reasons, we applied the DiFac hub and the ergonomic evaluation module to the door installation process in the automotive general assembly. The detail of the work process is as in the table below.

DiFac Solution

DiFac hub is a kind of engineering hub which operates on the web environment for the collaboration in the distributed environment. On the basis of DiFac hub, there is a PPRH schema of various engineering information, including human information for ergonomic analysis, which are from PDM systems. With this schema, DiFac hub provides the neutral XML file of PPRH information from PDM systems to each engineering systems and applications via web for collaboration in distributed engineering departments of automotive company.

Figure 1 presents the web environment of DiFac hub and the XML files generated by PPRH integrator.

Figure 2 presents the results of ergonomic simulation for the given working conditions with regard to the automotive general assembly tasks. The ergonomic analysis solution analyzes human movement pattern based on the developed digital human model and the PPRH information from the web environment of the DiFac hub.

Case Assessment

Strengths	*Weaknesses*
Well-applied PDM/PLM systems Well-applied digital virtual manufacturing Extensible schema of PPRH information Collaboration Environment via web Advanced digital human modeling technique	Existing out-of-date engineering tasks(Manual) Existing out-of-date HW and SW
Opportunities	*Threats*
Impossible to apply fully-automated production system—Needs of ergonomic analysis World-wide market—external engineering department	Huge and extremely various engineering information—Difficulty of integrated management

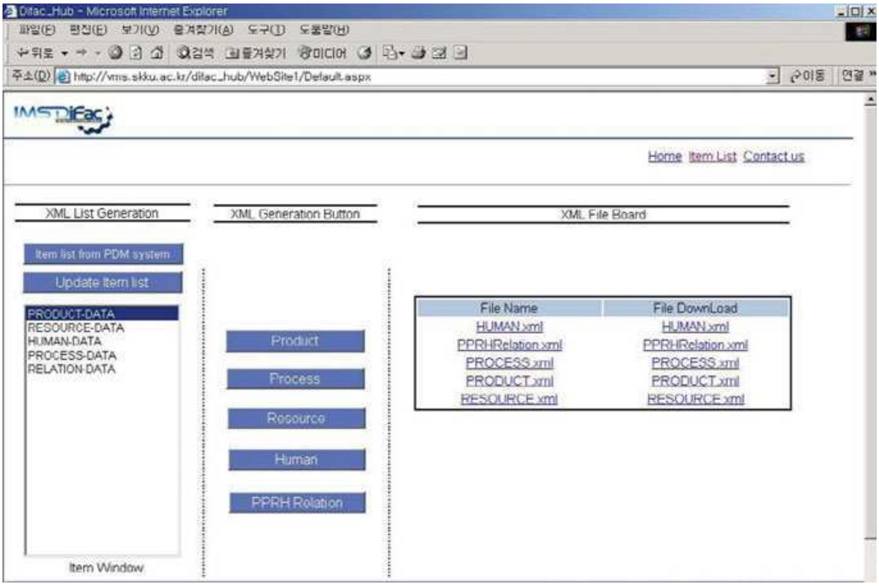

Fig. 22 Web environment of DiFac hub

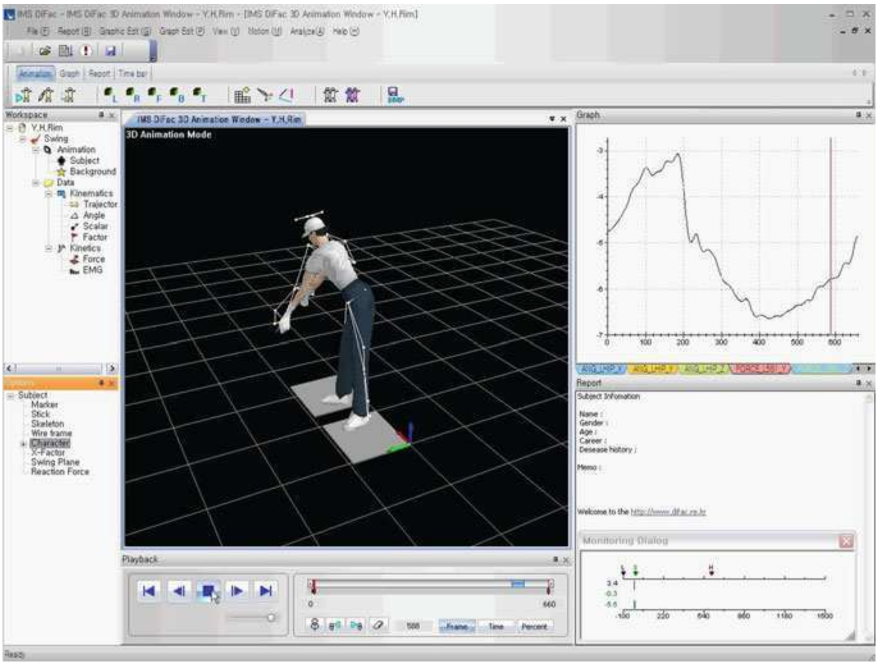

Fig. 23 Ergonomic analysis solution

- *Internally*: DiFac hub has extensible schema of PPRH information and it works on the web for the collaboration. The target automotive company already applied and keeps pursuing PDM/PLM system and digital virtual manufacturing technology. But, there are still out-of-date engineering tasks for manual analysis, and out-of-date HW and SW.

- *Externally*: In general, it is hard to apply fully-automated production system to automotive industry. So, there are needs of ergonomic analysis. And, for the world-wide market, collaboration in distributed environment is essential. But, with growth of society and related technology, the amount and variety of engineering information is increasing.

Future Perspectives

Nowadays, most of all technologies are becoming to be focussed on human and flexibility. In particular, there have been researches for human centralized manufacturing system. Also, for the flexibility of manufacturing system, integrated management and exchange among heterogeneous systems is essential in terms of PLM (product lifecycle management). DiFac hub supports collaboration via web and interoperability with PPRH schema. In addition, ergonomic analysis S/W incorporates ergonomic analysis into working conditions of the digital factory. So, there is possibility for applying DiFac Hub and ergonomic analysis S/W for other industries, for example, shipbuilding, semiconductor, electronic product, and construction.

Index

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