Intelligent manufacturing through participation

a Participative Simulation environment for Integral Manufacturing enterprise renewal

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IMS
HUMACS

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INTELLIGENT MANUFACTURING SYSTEMS

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Driving industrial networks

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IMS
ORGANIZATIONAL ASPECTS OF HUMAN-MACHINE COEXISTING SYSTEM

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Frans M. van Eijnatten

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Frans M. van Eijnatten (Ed.)

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The PSIM Consortium / TNO Arbeid, Hoofddorp, The Netherlands

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Preface

New market requirements, the development of ICT technologies, the constant need for efficiency and improved working conditions make it essential to apply the newest insights and experiences in optimizing the assembly process.

Several partners from all over the world have combined their expertise in the areas of ICT, Sociotechnique, Assembly Engineering and Ergonomics into an integrated approach whereby, with the worker' participation, assembly flow processes become more efficient and more human oriented.

This book describes essential elements of this approach and successful tests at Volvo in Sweden, Finland Post in Finland, Fiat in Italy, Yamatake in Japan, and Ford in the USA. These companies have widely opened their doors to share with you the results and improvements that have been achieved.

This book will help universities and knowledge institutions in gaining new insights on participative improvement process and ICT techniques that support this process. Companies that have assembly operations can benchmark their situation to that of others and generate ideas allowing them to better cope with changes in their environment.

It was an honour for TNO to be allowed to coordinate this PSIM project and introduce to you this innovative approach combining the best of ICT, Sociotechnique and Ergonomics.

Prof. dr. F.D. Pot
Director TNO Work and Employment

Hoofddorp, The Netherlands, March 2002

1. Global Perspectives of the PSIM Project

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Abstract. The PSIM project is viewed from global perspectives in relation to its global project HUMACS that is developed as an international joint research project under the IMS initiative. Following brief introduction to the HUMACS project, PSIM's challenge as a thrust for organizational knowledge creation and its interrelationship with the outcomes from HUMACS Japan are focused. The author writes down this chapter as international coordinator of the HUMACS project.

1.1 Introduction

Manufacturing industries are exposed to increasingly intensifying global competition in recent years and are in a trend to further automate their production facilities. Even in next-generation manufacturing systems, however, it will be unrealistic to expect perfectly unmanned factories. Human resource is a crucial factor in maintaining modernized manufacturing systems to a stable and profitable equilibrium.

In this context, how to help people working there effectively display their creativity and innovativeness is drawing attention as a prime determinant of corporate competitiveness. The spread of information technology and the expansion of networks are accelerating the standardization of manufacturing technologies. This means that differentiation by product or manufacturing process technology will inevitably be short-lived. This is why knowledge of people working for a company is said to be the only resource that can bring it a lasting competitive edge.

In order to make the most effective use of factory workers as human resources, it is imperative to restore their human dignity by freeing them from dehumanization, which is one of the evils of rationalization of production in recent years. The reason is that they will not be able to come up with creative or innovative ideas unless they can establish their identities in their workplace and get a sense of satisfaction or fulfillment from their jobs. This will also no doubt contribute to higher productivity by directly reducing human errors, labor accidents, and damage to health at work sites.

Under these circumstances the HUMACS project was launched aiming to address human-factors issues in human-machine coexistence in manufacturing industries. The PSIM project started later joining hands with this undertaking from European regions.

The contents of this paper are organized as follows: section 2 outlines the global HUMACS project; section 3 through 5 present topics representing PSIM's features that are supposed to be of global significance.

1.2 Global HUMACS Project

1.2.1 What is HUMACS?

The HUMACS project was originally proposed by Yamatake Corporation to be developed under the IMS program [1]. The acronym of the project stands for "organizational aspects of HUman-MAchine Coexisting Systems", and squarely tackles human and organizational issues encountered in manufacturing industries, which is associated with the fourth technical theme specified in the IMS Terms of Reference.

Thus HUMACS aims to pursue a practical methodology to establish an optimum relationship between human factors and manufacturing facilities based on ergonomical, informational and sociotechnical studies on next generation manufacturing systems. Specifically, it is a challenge to solve the following problems that are commonly perceived by manufacturers in relation to the requirements mentioned earlier for desirable human-centered manufacturing systems:

- How to mobilize the human power most effectively for modernized manufacturing,
- How to preserve and enhance technical skills for manufacturing,
- How to exploit information technology to resolve sociotechnical problems in manufacturing enterprises.

After the preceding studies conducted in the Japan region, an international consortium was formed with its project proposal endorsed as an IMS international project in February, 1997.

Under the umbrella name of HUMACS, its European version PSIM (Participative Simulation environment for Integral Manufacturing enterprise renewal) was defined. Its objectives are described in the project proposal [2] as follows: *"PSIM is a software environment for use in assembly operations and will be developed and pilot demonstrated in the project. PSIM uses a* P*articipative improvement process involving specialized staff, management and production personnel. PSIM shows* S*imulated assembly lines in state-of-the-art ICT. PSIM is on* I*ntegrated renewal, which means that technological, organizational, and human factors are all concerned in optimization. It is focused on intelligent* M*anufacturing to assist human and technological creativity."*

Overall improvements in manufacturing performance will arise from efforts to ensure the optimum coexistence of humans and machines based on the proper analysis and evaluation of the human factors. This research project was initiated to reflect such background and motives. It is not a mere pursuit of the optimum design of human-machine interfaces, or human computer interaction. It is a challenge to properly evaluate human factors from diverse angles, based on basic research in the organizational, sociological, and human engineering fields.

Yamatake Corporation, Japan, serves as International Coordinator of the project accommodating four regions effectively involved as: Switzerland (1 partner), EU and Norway (11 partners), Japan (6 partners), and USA (1 partner). The names of the current participants are listed at the tail of this paper. Increasingly active collaboration on development of technical themes has been taking place in particular between Europe and Japan regions, leading to the first-phase completion of the project scheduled for March, 2002.

1.2.2 Project Goal Image

Figure 1.1 shows the unified goal image of the international project in relation with platform technologies and backbone knowledge. In the center of the figure, 'human-factors centered manufacturing enterprise' is placed as a target object to be supported by a technical environment to be developed anew. The upward arrow symbolizes continuous improvement and ever-lasting evolution to be developed in a spiral way in such a manufacturing company. A company uses humans that operate in networks and need motivation. The target enterprise is the one where people involved give full play to their capabilities from every perspective with full sense of fulfillment and satisfaction.

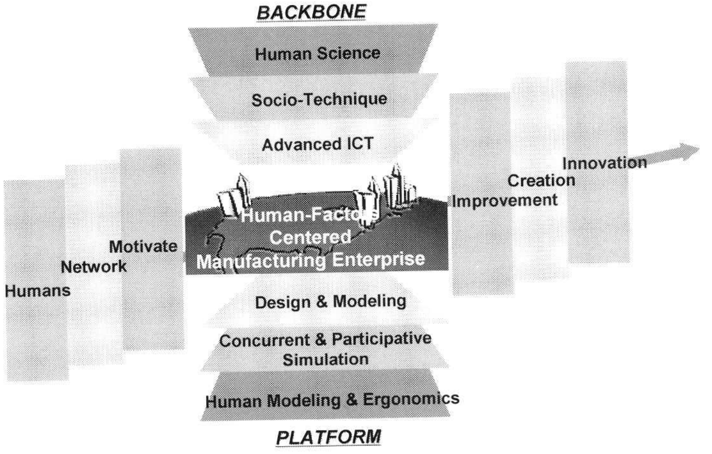

Figure 1.1 HUMACS Goal Image

For this support, three types of platforms are defined: The first one, 'Human Modeling and Ergonomics Platform' is essential because we need to evaluate human workloads from diversified perspectives, both physical and mental; The second, 'Concurrent and Participative Simulation Platform' is needed because we have to conduct simulation in a concurrent manner to cope with abrupt environmental changes, or to check in advance on new ideas for improvement, while also, this needs to be done through participation by all the people involved such as managers, designers, staffs, direct workers, and so forth; The third platform, 'Design and Modeling,' facilitates handing of such information as is not fully expressible by conventional means like documents and/or drawings, or considered belonging even to the realm of tacit knowledge, the most typical example of which will be an intrinsic concept to be shared in the course of collaboration between humans, or between humans and machines, and something like designers' intention.

In the meantime, backbone knowledge is needed in the field of human science, sociotechnique and advanced ICT. Human science here includes ergonomics, work science, and so forth. Enhancement of existing knowledge in the backbone knowledge area is requested in the course of the project development along with creation of new knowledge.

1.3 PSIM as a Thrust for Organizational Knowledge Creation

In a human-centered manufacturing factory or enterprise, an organizational strategy for knowledge management is of vital importance in terms of making the continuous improvement or ever-lasting evolution a reality by fully bringing out capabilities of individuals, and making a company not a rigid machine but a living organism.

A conventional interpretation of an organization as a mechanism for 'information processing' has a fundamental limitation; it does not really explain innovation. The organization should support creative individuals or provide contexts for them to create knowledge. Organizational knowledge creation is to be understood as a process that 'organizationally' amplifies the knowledge created by individuals and crystallizes it as a part of the knowledge network of the organization [3].

HUMACS comprehensively tackles on how to promote organizational knowledge creation by supporting the spiral-up activities as indicated in Figure 1.1. The organ- izational knowledge creation is closely related to workplace climate and corporate culture, or – in other words – traditional ways of organizational operation. There appears to be a sharp contrast between Western and Japanese styles in this regard.

In short, Western engineers tend to emphasize explicit knowledge based on a view of an organization as a mechanism for information processing, while the Japanese tend to stress tacit knowledge, where team working and participation have been common for years so as to encourage socialization of tacit knowledge as well as organizational learning in internalization in the course of knowledge conversion process. The tacit nature in Japanese organizational management may be best exemplified in the case of the Toyota Production System, in which, according to Spear and Bowen, some unspoken mechanism, so as to say, attributable to DNA must underlie coupled with its corporate culture [4].

Needless to say, there will be a limitation in organizationally innovative activity if we remain satisfied with methodology resorting to tacit dimensional procedures alone. What we have to do is to systematically help socialize tacit knowledge into explicit dimension thereby facilitating dynamic interaction between knowledge transfer patterns defined on Nonaka's SECI model [3] toward the ultimate goal of sustainable innovation.

PSIM is making a challenge to provide a solution for this theme that attracts global interest by developing a specific tool for positively supporting approaches to amplify knowledge in the upward spiral knowledge-creating process: from the individual, over the team to the organization. The key factors for a breakthrough in this approach are: participation, simulation, ICT architecture, and ontology. Specifically, a newly developed PSIM ontology facilitates interoperation and communication between applications (e.g., ERP, MES, Sociotechnical tools, Ergonomy tools [5]) and it allows us to integrate the related knowledge acquisition, discovery, and modeling efforts of the end-users within the context of their enterprise [6].

While the system environments developed by HUMACS Japan will as well contribute to cultivation of knowledge in the tacit dimension, PSIM plays a pivotal role serving as an engine in the entire spiral-up process to which the global HUMACS is committed.

1.4 Integration of the Outcomes from HUMACS Japan with the PSIM Environment

The PSIM project has developed a prototype system by fully utilizing advanced ICT in order to implement its essential concept mentioned in the preceding section. In addition to the basic concept of facilitating participation by all the people involved, the system environment has a state-of-the-art architecture that provides the following functional features:

(1) Evaluation of the current situation of working conditions by means of simulation technologies and VR technology, along with in-advance evaluation of possible improvement,

(2) Evaluation from the perspective of human-factors utilizing a variety of ergonomics and STSD tools [5],

(3) Commitment of ontology facilitating integration of different packages and appropriate navigation for right tools for right person [6].

It appears that, within the global HUMACS project, the development of a system environment conducted in PSIM stands largely on the second platform 'Concurrent and participative simulation' in Figure 1.1. As is easily seen above, however, it also has significant relevance to other platforms and backbone knowledge through development of ergonomic and STSD tools, and application of the state-of-the-art ICT expertise.

In the meantime, HUMACS Japan preceded several years to PSIM, and it has focused on the development of practical methodologies associated largely with the three platforms.

For 'Human-modeling and ergonomics' platform, Info-Ergonomics, which means a fusion of IT and ergonomics, has been created anew at Arisawa Lab at Yokohama National University establishing a simulation system capable enough for performing precise ergonomic evaluation [7]. This systems environment serves as a powerful vehicle to support an optimum design of human-machine coexisting systems in manufacturing. Meanwhile at Noro Lab at Waseda University, practical methods have been proposed for psychophysiological evaluation of desk work [8].

Arai Lab at Osaka University has developed a simulation environment with a real-time scheduler, which serves as a second platform, with the aim of implementing the specifications defined in Human-Oriented Manufacturing System (HOMS) [9]. The idea is being applied to upgrading of the surface mounting operation on printed wiring boards (PWB) assembly lines at Yamatake [10].

Itoh Lab at Sophia University and Yamatake jointly developed an Integrated Collaboration and Concurrent Engineering Environment (ICCEE) [11] in a bid to facilitate collaborative work by conquering difference in perspectives between participants. This environment falls on the third platform.

The ontology-based PSIM architecture is flexible enough to enable exchange of information between different tools or systems environments provided that respective ontology is defined compliant with PSIM ontology. The systems environments developed in HUMACS Japan could as well be integrated into the PSIM environment. This proves global applicability of the PSIM environment.

An assessment of feasibility in this regard was conducted for integration of a work process model for the surface mounting operation on PWB assembly lines at Yamatake into the PSIM environment with model representation settled in accordance with PSIM rules [12]. There is another case, though slightly different from system integration, on simulation and evaluation by the Info-Ergonomics simulation system performed on work samples obtained from TNO, producing a quantitative verification for appropriateness of ergonomic guidelines developed in the PSIM project [13].

1.5 Interregional Interaction

The final point worth mentioning from global perspectives of the PSIM project is that it belongs to an interregional joint research project under the IMS initiative.

The project successfully developed a prototype system as scheduled for the supporting environment mentioned earlier. Evaluation and discussion were held over the applicability of the pilot system not only within the European regions but also in Japan and USA, one for each.

These practices are meaningful since the PSIM environment intends to squarely deal with human and organizational aspects of working environments perception of which may be different depending on nationality, culture, tradition, and other historical and geographical backgrounds. The participatory approach, in particular, may be perceived in a different way between Europe and Japan, because the latter has tens of years of experience in participation by direct workers for improvement of work methods based on higher authority, in general, allowed to them for work design and manufacturing operation compared with the former.

In this sense, exchange of information on backbone knowledge shown in Figure 1.1 will be useful. Among contributions by HUMACS Japan in this area are study on a psychological adaptation model [14] and a proposal on a human-factors centered organizational model [15].

1.6 Conclusion

Our international joint research project has been in progress these five years since 1997, while sharing in common the tangible, easy-to-understand project goal image shown in Figure 1.1. There still remain a lot of issues to be resolved before reaching the ultimate goal specified in the project image. Admittedly, the achievements brought about so far alone could not directly produce industrial benefits.

It is true, however, that we have made a single but sound step forward toward the target defined on the framework of our project. What we have to do next is to add more tools by taking a building-block type approach, and to further enhance backbone knowledge, which we believe will lead to realization of attainment of the ultimate goal in the foreseeable future.

Based on such consideration, we have decided to mark a period to the current R&D phase at the end of March 2002. We sincerely hope the deliverables brought from the project would contribute to further research and development in the field concerned.

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2. Participative Simulation in the PSIM Project

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Abstract. This chapter describes the background and objectives of the IST project Participative Simulation environment for Integral Manufacturing enterprise renewal (PSIM). In the short run, PSIM aims to address the key issues that have to be resolved before a manufacturing renewal can be implemented. PSIM is focused on intelligent manufacturing in order to unleash human creativity supported by ICT technology. The long-term goal of PSIM is to show simulated assembly lines in a software environment. PSIM can be used to enable a participative improvement process involving specialized staff, management and production personnel. This chapter gives an overview of some basic ideas that provided both the theoretical and conceptual basis for the PSIM project.

2.1 Introduction

2.1.1 Participation and Democracy

Contemporary requirements put on companies to fulfill the needs of their clients and shareholders are numerous and high at the same time. Consequently, the challenge is to be innovative in markets and maximize efficiency. However, as was expected by many commentators, manufacturing enterprises find themselves in a highly competitive and global market place at the start of the 21^{st} century. In order to survive, these firms have to optimize their productions at an ever-progressing rate. In doing so, they have to confront a multitude of stakeholders' demands. In order to turn an innovative prototype into a manufacturable product at a much higher speed than ever before, companies need to continuously improve the process of product creation. At the same time, resulting prototypes of new products should fit in manufacturing systems that cost effectively can produce them.

In their struggle to cope with those new demands, most modern organizations are well underway to become knowledge-based enterprises. The above-mentioned trends presuppose the explicit managing of knowledge creation and knowledge processing. Drucker [1] and Quinn [2] – two researchers who pioneered in the field of Knowledge Management – advocate, that knowledge should be seen as a prime resource for competitive advantage in current and future competition. They emphasize that the management of knowledge should be coordinated at the highest level, preferably at the level of the company as a whole. Of course, this managerial activity is not executed in a vacuum. The political context is of major importance here.

A democracy can be seen as the dominant socio-political regime in all developed countries, nowadays. Democracy is defined as a system of governance in which people actively take part in the decision-making process. Two archetypes can be distinguished: Representative Democracy and Participative Democracy.

Representative Democracy is defined by Emery [3: p. 1] as *"choosing by voting from among people who offer themselves as candidates to be our representatives."* Participative Democracy is defined by Emery & Emery [4: p. 100] as *"locating responsibility for coordination clearly and firmly with those whose efforts require coordination."*

Within a democratic system participation of employees easily can take multiple forms. In a company context participation is defined as a process which allows employees to exert some influence in improving their work and the conditions under which they work [4]. According to Heller et al. [4: p. 45] competence (capability) is: *"both a requirement for and a consequence of participation."* It is a requirement because participation needs a minimum level of skills in order to be effective. At the same time it is a consequence because participation enhances the skills levels of those involved. Participation as a process has advantageous results for both the individual – in terms of capability and job satisfaction, and for the organization – in terms of core competence, increased efficiency and higher effectiveness.

In a *Representative Democracy* the influence of people on decision-making is rather indirect. This form, we call 'political participation,' is defined by Abrahamsson [6: pp. 186/189] as *"participation involving the right to control organization's executive (...) / involvement in high-level goal setting and long-term planning."*

In a *Participative Democracy* the influence of people on decision-making is as direct as possible. This form, we call 'socio-technical participation,' is defined by Abrahamsson [6: p. 189] as *"participation in the organization's production, i.e., in the implementation of decisions taken on higher levels."*

Representative Democracy and Participative Democracy can both be concurrently present in an enterprise, on different levels of aggregation. Familiar examples are the Works Council functioning at the higher or enterprise level, and self-managed work teams operating at the lower or shop-floor level. In a literature survey on Participatory Ergonomics [7] another more practical aspect of participation is stressed: direct involvement of the end users and groups influencing the improvement process increases the chance of successful implementation.

2.1.2 Participative Simulation in Manufacturing Design and Process

End-user involvement in design and innovation is increasingly being advocated. Proponents argue that a participative approach can have important benefits for both the end users and the organization as well. In particular, two direct advantages are commonly referred to. First, there is the point that end users have unique knowledge and experiences of their work. Their involvement will, therefore, provide a clearer understanding of both the types of problems being encountered, and the solutions that will be appropriate. Second, involving end users in analysis, development and implementation of a change will generate greater feelings of solutions' ownership, and thus may breed a greater commitment to the changes being implemented [7].

As said before, in organizational design and management ever more attention is paid to successful improvement processes, enabled by socio-technical participation [8]. Some benefits of direct participation are recognized in its contribution to a smooth mutual communication between management and employees. Socio-technical participation may be considered in the development, the implementation and the application of an improvement project. To boost direct participation, it is recommended to allow the employees to establish cross-departmental task teams – which deal with improvement issues – and to engage in 'participative simulation.' The European Foundation for the Improvement of Living and Working Conditions [9: p. 2] reports that direct participation in organizations most often leads to quality improvements (90% of the cases), to reduction of throughput times (60% of the cases), and to reduction of costs (60% of the cases).

In 'participative simulation,' workers exert direct influence over the product and process designs by bringing in their tacit knowledge – to combine it with expert knowledge – and to put the blend of both insights to the test. The moment these experimenting and problem-solving activities are supported by an attractive ICT interface, the resulting continuous improvement process may become even more intrinsically motivating for the work force [10]. Besides, it also will contribute to the competitive advantage of the enterprise.

Participative simulation can help to improve the work of a manufacturing work force. A powerful integrated digital environment that would bring to life a virtual copy of the actual manufacturing system represents an interesting facility [11] [12] [13]. It would enable profound analysis of possible interventions in the real manufacturing system, and ensure more efficient improvement efforts [14].

In participative simulation, the applied tools should as well produce images (mere descriptions) of all sorts of designs, as be able to compare their respective qualities (evaluations) and suggest improvements (reflections, and regulative actions). In order to accomplish that, the tools should be upgraded to expert bases. Although the technical aim in advanced intelligent manufacturing systems is to accomplish a more predictable work system, experiences from the social sciences indicate, that especially where humans are concerned, absolute norms and solid predictability are limited, and centralized control is not more than a utopia.

In PSIM, holistic thinking ('looking at the whole') and analytic thinking ('looking at the parts') are combined, at different levels of aggregation. At the highest level, an image of the whole system is created, and its functioning in its environment is evaluated ('looking outwards'). At the lower levels, parts and their inter-relation-ships are distinguished and analyzed in detail ('looking inwards'). It is the aim of the specially designed ICT architecture to guarantee that all sorts of simulation tools can be easily plugged in, in order to support the processes of analyzing and synthesizing in a context of dialogue. The idea is to tap and store both the explicit and implicit knowledge of the employees. In Box 2.1 Participative Simulation is defined.

The goal of Participative Simulation in general, and of the respective simulation tools in particular is not to deliver factual solutions to the users, but rather to support them to reflect on their work situation, and to elaborate their own tailor-made solutions.

Participative Simulation is:

- *A dialogue environment for the exchange of tacit and explicit knowledge about the design and control of production systems,*
- *A dialogue environment for the development or renewal of workplaces,*
- *An ICT environment which supports dialogue between workers of different levels in the organization,*
- *A means to stimulate thinking processes about renewal,*
- *A groupware tool,*
- *A management information system,*
- *A game to develop common understanding of organizations,*
- *Based on an integral approach.*

Participative Simulation is not:

- *A mathematical tool,*
- *An optimalization tool,*
- *An actual individual simulation (though simulation can be used in participative simulation as a tool),*
- *A generic system,*
- *Based on a fragmented approach.*

Box 2.1 A Definition of Participative Simulation

2.1.3 Intelligent Manufacturing Systems and Assembly Operations

Although the idea of participative simulation is not new, the potential of this method in organizations was rather restricted, for a long time. It is the development of modern ICT technologies that expands the participative simulation potentials with an order of magnitude. The local knowledge of workers, locked in their traditions and work habits, may be successfully tapped and communicated by using ICT-supported participative simulation. For instance, the intended ICT-enhanced participative simulation prototype will be multi-media: it will use narratives, photos, videos, computer graphics, illustrations, figures, games, performance indicators, and animations. It can be used both by managers, technical staff and workers as well.

Up until the present day, the total number of users of simulation tools in the domain of work organization has been pretty low. In so far simulation tools were used to reflect on possible interventions, they were often stand-alone and did not support an integrated perspective on possible changes to practice. One of the major problems was and still is to generate a common description, e.g. a future workstation or situation on the shop floor in the existing plant, and let people from different backgrounds participate in the analysis. In the past, these tools often reflected a state of the business that was already outdated.

The decreasing level of specificity in the material components of manufacturing systems which are based on openness and modularity, implies that the competitive advantage of the system as a whole has to be found elsewhere: The human operator and his working methods came to stand out more prominently. It is known, that these work methods develop on the basis of complex and unique 'know-how' based on organizational cultures and strategies, and consequently, are not easily imitated [15] [16].

The centrality of the human factor calls for 'Intellectual Capital Management'. Although Intellectual Capital Management has received a lot of attention in professional service organizations – and evolved there into a hype – it has been almost completely neglected in assembly. If a company wants to make efficient use of knowledge and intends to cause the knowledge, skills and experience of its employees to become more effective with respect to achieving organizational goals, the two perspectives on Intellectual Capital Management – organizational and individual competencies – should be aligned. The two perspectives become compleenary to each other. Unfortunately, current theory does not provide much guidance on how to accomplish that.

Typically, most researchers on core competencies are not explicitly stating their level of analysis: They do not clearly distinguish organizational from individual competencies. Core competencies are discussed as collection and integration of skills and technology of a company as a whole (across diverse business units). Individual employees are seen as the 'skills carriers' that embody the competencies [17] [18]. Theorists recognize that in practice a mechanism for allocating skills is seriously lacking. Hamel and Prahalad [17: p. 89] write: *"We find it ironic that top management devotes so much attention to the capital budgeting process, yet typically has no comparable mechanism for allocating the human skills that embody core competencies."* But they do not discuss any method or approach how to fill in the role of individual capabilities, with respect to strategic objectives and competencies of an enterprise. A similar conclusion can be drawn from literature on individual capabilities: A clear connection with organizational goals and core competencies is lacking.

To take a step forward, we propose an approach based on the idea that the power of knowledge is not so much leveraged by exclusively possessing that knowledge. It is far more important to know, how to allocate knowledge for productive use [1]. Nonaka and Takeuchi [19: p. 59] discuss the role of an organization in allocating knowledge as follows: *"The organization supports creative individuals or provides contexts for them to create knowledge. Organizational knowledge creation, therefore, should be understood as a process that 'organizationally' amplifies the knowledge created by individuals and crystallizes it as a part of the knowledge network of the organization."* The successful execution of this organizational activity can be regarded as a core competence.

To become a competitive strength, the work methods should reflect all manufacturing expertise that is available in an organization, not only the insights of a privileged process engineering elite. In the design of new systems, or reconfiguring of existing ones, interdisciplinary participative reflection should be encouraged and supported, to influence the manufacturing organization primarily as a knowledge processing entity. In order to accomplish this goal, strategic action through investments in a proper environment is needed. Computerized facilities for 'participative simulation' could be instrumental in this respect.

ICT can support communication by providing highly visual representations of abstract processes, which conduce to a common ground for dialogues. In this respect, 'simulation' is defined as the construction and use of a computer based representation or model of some part of the real world as a substitute vehicle for experiment and behavior prediction. It offers an attractive opportunity for engineers, planners, managers and production teams to try out ideas or commitment to a course of action, in advance [20].

2.2 Contribution to Intelligent Manufacturing Systems

2.2.1 The PSIM Project

PSIM is an Information Society Technology (IST) project sponsored by the Fifth Framework initiative of the European Commission that develops and pilot-demonstrates a Participative Simulation environment for Integral Manufacturing enterprise renewal. PSIM runs under the umbrella of the HUMACS program. HUMACS is an abbrevation of Organizational Aspects of HUman-MAchine Coexisting Systems, and is part of Intelligent Manufacturing Systems (IMS), a global industry-led Research and Development program. The PSIM/HUMACS consortium consists of twelve European, eight Japanese, four American and three Canadian partners.

PSIM aims at the development of a simulation environment for use in assembly operations, and wants to advance integral renewal in a competitive, changing environment by supporting continuous improvement processes. In this project simulated assembly lines are developed and pilot-demonstrated in a software environment, involving both specialized staff, management and production personnel as well. By the end of the PSIM project a structure for the software environment as well as a process of implementation have been developed which are proven to be operational in three European-Union pilot sites. Also they have been studied with other HUMACS partners, including other potential PSIM users in the European Union, Switzerland, Japan, and the USA. We expect a 15% efficiency improvement at the three pilot sites and 20% better work satisfaction due to better working conditions, in about two years. Another expectation of the PSIM project is, that the process of participative simulation can be shortened and be made of a much higher quality because of the integrated use of ICT technology.

In order to test the basic ideas, the PSIM project will actively engage into a reality check, using several industrial test sites in Europe, Japan, and the USA. To demonstrate the concept, PSIM will concentrate on expertise from the domains of Socio-Technical Systems Design and Ergonomics. The first key design methodology is *Socio-Technical Systems Design (STSD)*, which is concerned with the optimization and integration of the human factor in manufacturing systems, predominantly at the work group, departmental and organizational levels. It aims at improving the quality of work and organization, simultaneously, through adaptation or fundamental re-design of contents and composition of technology and human tasks [21]. The Dutch STSD variant of Integral Organizational Renewal (IOR) offers dedicated design concepts, methods and strategies. These can be used for diagnosing and improving existing production structures in order to make optimal use of the human factor, while at the same time enabling a multitude of design objectives (i.e. innovation, flexibility, controllability and quality of work). STSD can successfully support ICT-driven simulation of organizational renewal in a development activity game environ-ment. Within the socio-technical framework, also a method was developed that specifically addresses the issue of allocating tasks between humans and technology, i.e. defining the degree of automation. Key to this so-called KOMPASS method, that was developed at ETH, are design criteria at the level of the work system, the individual task, and the human-machine interface, which can be used in system modeling and simulation [22] [23]. KOMPASS also focuses on the design of indi-vidual work tasks by using theories about work psychology such as action theory, and theories about work motivation.

While the focus of the socio-technical framework is on the human-technology interaction, the more specific aspects of fitting tasks and technology to human operators is dealt with by the second key design methodology, the *Ergonomic Approach*, which is concerned with optimizing the tasks, technical systems and work stations in order to improve human performance and to reduce mental and physical workloads. Data from the European Foundation for the Improvement of Living and Working Conditions [9] indicate that a rise in 'time pressure' has taken place throughout Europe. Approximately 30% of the workers in the European Union are involved in painful and tiring postures for more than half of their working day and 40% of the workers are exposed to short repetitive tasks, which often lead to reduced quality, productivity, complaints or even sick leave. A recent survey reports on the work-relatedness of drop out from work due to psychological dys-functioning. Some important aspects in the reduction of workload are the good fit between task and personality, possibilities to develop and regulate your own work. Therefore an important function in PSIM is envisioned that will warn users when unacceptable workload for humans and teams is anticipated in a particular work system design. Users of PSIM will be warned for physical and mental hazards in designs of a workflow or workstation.

2.2.2 Method

The PSIM project followed a systematic approach, based on two phases:

- *Development of the PSIM Prototype:* The PSIM prototype was built by nine partners: five European universities (TU/e, Eindhoven, The Netherlands; RWTH, Aachen, Germany; Chalmers, Göthenburg, Sweden; UOP, Patras, Greece; and ETH, Zürich, Switzerland); two research institutions (TNO, Hoofddorp, The Netherlands; FIOH, Helsinki, Finland); and two software developers (Baan, Barneveld, The Netherlands; GFI Consulting, Turin, Italy). The PSIM prototype was built in four main work packages: Ontology, Navigator, Tools, and Integration, over a period of one and a half years,

- *Test of the PSIM Prototype:* The test of the PSIM prototype was prepared in two work packages: Pilot Requirements and Pilot Demo, using the 'Focus-Migration' method. Three industrial partners participated in the test: Finland Post, Helsinki, Finland (logistic industry); Volvo, Göthenburg, Sweden (automotive); and Fiat, Turin, Italy (automotive). Each of them offered one single pilot site for testing and studying the developed prototype. In the context of HUMACS two additional companies offered opportunities to test the PSIM tool: Yamatake, Tokio, Japan (electronic industry); and Ford, Detroit, USA (automotive). The test site requirements were determined by using an inductive method ('as is' analysis of tasks, work organization, and work roles), and the derivation of demands for PSIM (assembly development, ergonomic and socio-technical assessment) was achieved by means of a survey.

The PSIM prototype was tested in the before-mentioned five companies – using the Ergotool and / or STSD tool – addressing only one single PSIM goal (improvement). The PSIM prototype was explicitly developed and prepared for these individual tests, only. The rationale behind this was that the consortium wanted to test the feasibility of the principle ('proof of concept'), in the first place.

2.2.3 Results

The Participative Simulation (PSIM) prototype that was developed, consists of a number of integrated parts. The complete tool contains an innovative ICT environment composed of an ontology, a procedure or navigator, and an OLAP (On-Line Analytical Processing) integrator, a set of specific work organization analysis and design tools (i.e., with respect to Ergonomics and Socio-Technical Systems), and a well-developed handbook in which detailed procedures for alternative applications are worked out in detail. In it the user will find an extensive description of the settings for, the conditions of, and the individual tools in the PSIM prototype.

The PSIM environment consists of a state-of-the-art ICT architecture that enables both technical communication between the different tools databases and access for different users by providing a user interface that is sensitive to the individual profiles, jobs, tasks and specific work contexts. It supports an integral approach by relating models and data to a virtual copy of the actual, imagined, or proposed manufacturing system. The ontology thus encourages integration, which is focused on the holistic consideration of human, organizational and technical aspects. The navigator enacts the PSIM procedure by providing the right tool, with the right data, in the right place, and with the best user interface. Between the tools and the navigator a communication layer is built to insure the coherence of the exchange of data between the individual tools. The PSIM-user roles as mapped in the navigator are explicitly defined in a way that supports inter-disciplinary work in project teams.

The individual tools that are worked out in detail, are exclusively dealing with Ergonomics and Socio-Technical Systems Design. They offer users opportunities to self-assess and self-design their work systems and methods of work, preferably in a multi-disciplinary work group context. The aim is to reach consensus regarding design goals and solutions. The tools allow its users to store analysis and evaluation data and outcomes, thus enabling the users to keep track of changes and effects of changes for a particular work process.

The PSIM handbook explains to the user in simple language how the PSIM environment works, what sorts of applications are possible, which specialized tools are available, and what kind of solutions they may provide. The PSIM procedure shows different applications, i.e., continuous improvement, renewal, fast innovation, and implementation of new methods of work, and guides the users towards the right tools. For each of these applications it presents respective steps to follow in a 'deep slice' project group, using a participative approach. As an extra, it offers some help with respect to time management, and illustrates the procedural integration of the work of different project groups. Embedded in the PSIM procedure is a general enterprise model. The PSIM procedure consists of three phases: 1) Defining current problems and future objectives for which solutions must be designed or found, and selecting or marking out respective work systems which need further consideration; 2) Detailed analysis, assessment, and evaluation of the work system(s) under consideration; 3) Creation or selection, elaboration and evaluation of tailor-made design solutions.

Initially, the Ergo- and STSD tools were developed into paper-and-pencil prototypes with manual functionality, limited-use procedures and provisional user support. They were tested in individual workshops at Finish Post and Volvo. On the basis of these tests the prototypes were refined and prepared for ICT support.

The refined PSIM procedure and the ICT-supported versions of Ergo- and STSD tools were tested in three companies at the end of 2002. In all test sites the PSIM procedure proved to be an essential part. Both steps of analyzing the existing situation and discussing ideas for improvement with a group of engineers, operators, management and designers were evaluated positively. In evaluating the procedure companies mentioned that a facilitator is very much needed. The Ergonomic and Socio-Technical Systems Design experts proved to be essential in the processes of inviting the users to follow the procedure, and in explaining some backgrounds of the simulation. Also, the visualization support (by use of a video) was evaluated positively. Actual tools differences were observed between companies. Companies that were not used to apply Ergonomics evaluated the Ergo tool more positive then those who were. The application of the mental workload module in the Ergo tool, and the application of the STSD tool resulted in the largest number of new improvement ideas. Both tools were evaluated very positively. Other parts of the tools were nice, but it was the question whether they would replace existing checklists, methods or software that are already used by companies. Also, it was mentioned that the application of the STSD tool was rather time consuming.

2.3 Conclusions

It is expected that the PSIM project will produce a breakthrough in both Participative Simulation method and ICT architecture, including the ontology (see Chapter 3). It is anticipated, that the ICT architecture will enable other knowledge domains to be integrated in the PSIM tool as modules quite easily. A potential candidate for inclusion is the Design of Workspace decision-making model that resulted from the Brite-Euram III, Work-space II Thematic Network BET2-516, 4th Framework Program [24], that will add decision-making about facility management to the Participative Simulation environment.

The lessons learned thus far concentrate on the topics of interdisciplinary preparation and communication. It appeared a necessity to visit the test sites with a full multi-disciplinary team, in order to research the requirements, in order to develop and test the tool appropriately. During the development of the ontology, major differences in concepts and methodologies among the experts came to the fore. The readiness to take enough time to dialogue about these issues extensively, proved a prerequisite to solve these issues. It offered a basis for a successful completion of the PSIM project.

As to main barriers for adoption, a problem could be the overall attractiveness of the simulation tool for the end users, or the modest level of penetration of computers in assembly operations. Also, the generality of the tool may be questioned, in specific assembly environments.

2.4 Discussion

The PSIM project was a big success, both from an ICT point of view (see Chapter 3), and from an organizational learning perspective, as well. Participative Simulation appeared to be a powerful way to involve people in the renewal of their enterprise.

Also from a national cultures perspective the usability of PSIM was interesting. Hofstede distinguishes between four basic dimensions that characterize national cultures [25]: the orientation to authority (power distance), the integration of individuals in groups (individualism / collectivism), the actual distribution of roles between sexes (masculinity / femininity), and the preference for stability (uncertainty avoidance). Extensive research by Hofstede revealed that national cultures differ on those four dimensions, significantly [25]. Cultural differences may have influenced the usability of the PSIM tools in either Europe, Japan or the USA. Finland and Sweden are classified by Hofstede as extremely feminine cultures, while Japan, Italy, and the USA are characterized as more masculine cultures, resulting in more individual competition. Power distances are moderate in most before-mentioned countries except for Finland where preferences for equality are extremely high, resulting in democratic leadership and minimal centralisation. Individualism is highest in the USA, Italy and Sweden, resulting in individual based incentives, and moderate in Finland and Japan. Uncertainty avoidance is highest in Japan, and lowest in Sweden, influencing differentially the degree of formalization and personal risks.

Although all PSIM tool tests were administered in an open and friendly atmosphere, some cultural effects may have been observed, embedded in the specific work organization context.

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3. The PSIM Environment Architecture

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Abstract. This chapter describes the architecture of the PSIM environment. It briefly presents the PSIM objectives and the role the PSIM environment plays in meeting these objectives. It then states the role and place of each of technological components of the environment: the ontology, the navigator and integration.

3.1 Introduction

The PSIM project addresses the fourth technical theme of IMS, Human/Organizational/Social issues. It focuses on improving the capabilities of the manufacturing workforce, thus developing an enhanced environment – named PSIM environment – able to capture, develop and enable accessing the 'enterprise technical knowledge'. The main objective of the PSIM environment is to support involvement of human talents and preserve and enhance technical skills by exploiting information technology, mainly the Internet computing paradigm, to solve socio-technical problems in manufacturing enterprises.

3.1.1 An Environment, Not a Tool

To support specific enterprise activities, like design, management, production control, etc., many tools have been developed. Nevertheless, till now, they are not integrated to offer to the worker an overall view of the context in which he is asked to operate. Tools, used separately for specific purposes, are not able to drive the user to a global solution: they do not enable the evaluation of the impact of a choice or decision on the overall context and the observation of the problem from another (broader) point of view than the one considered by each specific tool (technological, organizational, financial, etc. ...).

Of course, it is not worthwhile to implement a single tool able to support, with a 360° approach, all activities and functions of any particular enterprise. On the contrary, each specific theme requires a specific and optimized tool, built by experts in the theme's knowledge domain. And each enterprise requires a particular blend of themes to be addressed when improving its operations. Moreover, this blend changes as the enterprise evolves and competes in changing markets.

From its outset, the goal of PSIM was a prototype demonstration of an *ICT-enabled environment* that can enable stakeholders to integrate the vision and the results of several tools, such that choices and decisions that are optimized against the whole enterprise context and coherent with all different points of view, can be based on the application of several precise tools, each one aimed at providing specific answers to specific needs.

3.1.2 An Environment for Enhanced Participation and Management

A human's decision level is limited by the lack of coherent and exhaustive information. If a worker were aware of the impact of his choices on the overall situation, he could mediate his decisions with colleagues and with any other actor impacted by these choices. Therefore, to enable participation, a possibility of expressing and sharing opinions should be offered to any workgroup aiming to a common objective. This means that a certain number of workers, physically gathered round a table or virtually working as a group supported by IT technology, should be able to give each other visibility on problems and possible solutions, to share data and exchange information. Participation means active and integrated interaction among *all* actors and exchange of experiences to achieve common goals, not simply group-ware management of individually elaborated documents.

An environment enabling such a work approach will, therefore, represent a powerful support to the management and optimization of operative realities, by supporting decisions and enabling checking alternative operative solutions from all points of view against the final global objective. Moreover, such an environment, to support Company Integral Renewal, and reflect human values as well, needs to include concepts coming from the ergonomic and socio-technical disciplines, as argued in other chapters of this book.

3.1.3 The PSIM Environment Prototype: Design Objectives

The PSIM environment prototype has therefore been designed to be:

- *Easy to adapt to enterprise specific technologies*: the environment is able to integrate, whenever it is possible, those tools that the workers inside the company are used to work with,
- *Easy to adapt to different work contexts*: the environment supports the use of different languages and approaches to retrieve and integrate different experiences and competencies,
- *Transparent against Enterprise Information Systems*: the environment is able to access Enterprise Data and Processes through a standardized Reference Framework mapping the Enterprise according with a predefined modeling methodology.

3.1.4 Overview of This Chapter

This chapter gives an overall view of the PSIM-environment, and describes the functional integration and interactions between Ontology, Navigator and Integration. The next section presents the general architecture and the different perspectives used to describe the PSIM environment. Each description focuses on the joint working of the main technical components of the PSIM environment. Each component is described in detail in another chapter of this book. This chapter is an abridged and modified version of Part 1 of PSIM Deliverable D2.2 [1].

3.2 PSIM Environment from Different Perspectives

3.2.1 General Architecture

Ontology, Navigator and Integration are the main technological components of the PSIM Environment. In the ontology the whole enterprise, or that part of it significant to the specific context to be supported, is described both according with a standard enterprise modeling methodology (CIMOSA [2]– ENV40003 [3]), and according to a well-defined ontology [4].

As shown in Figure 3.1, the PSIM environment establishes links between stakeholders, enterprise databases and different analysis tools. Three ontology-based components support the navigator in realizing the necessary links:

- *The Reference Language*: A central component, which is structured by the PSIM ontology. The reference language is an extension of the PSIM ontology that supports the definition of two models that are particular to the organization: the *enterprise primary process model* and the *management process model* (PSIM procedure),
- A *PSIM user interface manager* component, allowing the users to access the system in their language, or more precisely the community language they belong to. This interface is built by the use of the mechanism of term mapping. The term-mapping is based on glossaries elaborated by domain experts of a community. Each term of the glossary is mapped to concepts of the reference language,
- A *Communication Layer* allowing, via translators, interaction between different software components such as tools and databases.

The PSIM-user interface manager component allows the sharing of information between different users without forcing them to learn the reference language, neither to learn the languages used in other communities. The communication layer manages the exchange of data between tools used in different enterprise analyses.

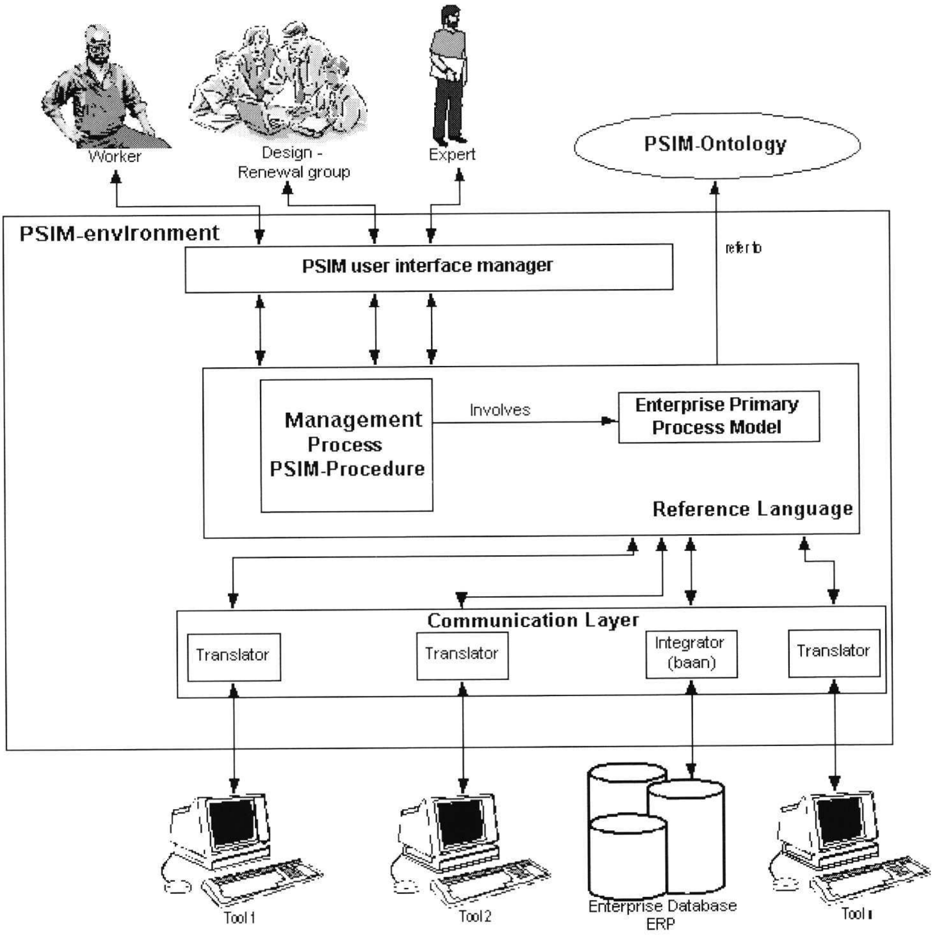

Figure 3.1 PSIM General Architecture

The Navigator is a clever interface between the Enterprise, its processes, data and objectives, and each worker, his job, capabilities, work environment and support tools.

The Integration module extracts and gathers most company specific data directly from the Enterprise Information Systems to make them available to the Ontology in a structured way. More details of the issues related to this integration are given in another chapter.

3.2.2 Reconciling the Points of View of Different Actors

Different stakeholders look at the PSIM-environment from different viewpoints. For each of them a clear understanding has to be provided on where and how PSIM concepts and objectives are mapped and enacted by the PSIM-environment. How and according to which approach this environment will access and provide information and enact support tools in order to satisfy, from a technological, organizational, ergonomic and socio-technical point of view, all the objectives and requirements any actor inside an enterprise – a worker, a designer, a manager – may have in performing activities. The views that are analyzed and detailed are:

- *The Operative Context View* describing the relationships between workers, at any level and with whichever duty within the factory, and work environments, the worker's needs and the provided support by the PSIM-environment,
- *The End User View* describing the way a generic user faces PSIM-environment, which kind of tools he will be supported by and by means of which user interfaces,
- *The Methodological View* describing the way by which a methodological approach will support integration of different views and tools into a common reference framework,
- *The Architectural View* describing technical solutions to implement, customize and enact the framework to become the engine of the Participative Simulation Environment.

3.2.2.1 The Operative Context View

In the *Operative Context View* are defined the relationships between each worker, his job, tasks and activities (actions) to be performed, and the information, the tools and any other support he will need to accomplish them.

- A *worker* has several tasks to accomplish, according with his capabilities and his position inside the company,
- A *task (activity)* is a structured sequence of *actions* (steps) leading to a specific result, in accordance with company objectives,
- A *job* is the ensemble of all the *tasks* a *worker* is required to accomplish,
- Each *worker* has his own *behavioral model* (derived from his skill, cultural and social life context, national regulation, etc.) in performing a specific *action (step)*,
- A *PSIM procedure* is the description of how and supported by which tools a specific *task (activity)* has to be performed and may be optimized against several perspectives.

From these definitions comes that – to support any worker – each specific PSIM procedure has to be customized according to the worker's behavioral models in performing the actions that compose the task.

Moreover, as a task is a structured sequence of actions (steps), a PSIM procedure is a structured sequence of elementary procedures, each one related to a specific action, describing how and by using which tools a specific action has to be performed and, eventually, optimized in order to satisfy its results against all objectives both at company and at single worker level.

Tasks and PSIM procedures may, in fact, be enacted to support either an 'operative process', or an 'improvement or renewal process'. We call *operative pro-*

cesses all enterprise processes during the *run phase* of their life cycle. Therefore, the design process, applied to new products and/or manufacturing systems, has to be considered an operative process. We call *improvement or renewal processes* all enterprise processes during the *design and/or optimizing phase* of their life cycle. Therefore, the manufacturing process, when subject to redesign and/or optimizing activities, has to be considered an improvement or renewal process. For a more complete description of enterprise entities life histories and their mutual relationships, see GERAM [5].

PSIM procedures differ from normally used enterprise task procedures either because they meet ergonomic or socio-technical soundness criteria expressed in the PSIM handbook, or because they integrate the socio-technical or ergonomic tools within the tools normally used to support operative needs.

3.2.2.2 The End User View

The *End User View* defines the way each worker approaches PSIM environment, which tools he will be supported by and with which user interfaces, which information he will be given and whichever other support he will be provided to accomplish his job.

When a user introduces himself to PSIM environment, via the Navigator, he will be informed of the tasks he is allowed and/or required to perform at that moment, according with his job description. The worker, then, chooses which task he wants to perform and the PSIM environment will select the PSIM procedure specifically defined to support him in taking decisions and/or making the best choices while performing the chosen task. PSIM procedures, in fact, are designed to support workers in performing tasks by suggesting how and by means of which tools they can take care, from all points of view, of newly arising or already existing problems in performing specific actions.

The Navigator will then start, according with the specific PSIM procedure, all suitable tools, in the right sequence. Each tool will be fed by the Navigator, with the information related to the specific action, in the specific task to be performed by that user at that point in time. All these specialized data are found by the Navigator using the ontology-based components.

For what concerns the data and the environment, we have to distinguish between a worker performing an action belonging either to an operative or to an improvement or renewal process. In principle, each worker may afford the tasks defined by his job from two different perspectives: an 'operative perspective' as well as an 'improvement or renewal perspective'. This means that, in performing his work, an actor may be asked to cover different roles:

- to act as an *operator*, that is to perform a specific action,
- to act as a *decision maker*, that is to make operative, organizational and/or technical choices,
- to act as a *designer*, that is to reengineer and improve the way in which an action is performed.

According with the role he is playing, he will be supported by different tools working on different kinds of data, in different work environments. When acting as an operator, he will operate in the *real enterprise environment*, supported by tools loaded with run time data and operating on real enterprise information systems. When acting as a decision maker or as a designer, he will operate in the *virtual enterprise environment*, supported by tools loaded with virtual data, eventually corresponding to the present real situation, and operating on a virtual environment for a what if analysis.

3.2.2.3 The Methodological View

Two parallel contexts of work matter for the end-users: the real and the virtual one, each with their own data. This section describes how these two contexts of work are mapped into the ontology-based components.

The Methodological View defines which information is mapped into the ontology-based components, and how data are related to each other.

In the ontology, and following ENV 40003 conventions [3], the information defining a specific Enterprise is mapped at three definition levels. At *generic level*, concepts like processes, activities, resources, definitions coming from the ergonomic and socio-technical fields and their mutual relationships, are defined as standardized generic entities, according with the chosen modeling methodology. At *partial level* generic concepts are gathered and specified according with the kind of enterprise and context PSIM environment has to support. The generic and partial levels represent the *Reference Framework* according to which specific company data will be mapped. At *particular level*, according to the *Reference Framework* predefined schema, data describing a specific reality will be directly input or simply addressed in the databases used by the different Enterprise Information Systems.

Inside the ontology, according with the reference schema, will be mapped any additional information and relationship, necessary to support the *Navigator* in providing the desired PSIM functionalities, according with Ergonomic and Socio-technical requirements. This requires that the enterprise is mapped inside the *ontology*, in terms of: *actions* (named steps in the ontology); *tasks* (named activities in the ontology); *jobs* (that relate, in the ontology, the activities contained in each task defined in the job, to specific end users); *capabilities* (necessary to perform the activity of supporting, may be together with other tools, a guy in performing an action contained in a task); *end users* (named human resource objects in the ontology) and their particular characteristics.

Moreover, to be able to support a *worker* in his acting as both an *operator* and a *decision maker*, the parallel and coherent realities corresponding, respectively, to a real and a virtual enterprise, must be mapped into the ontology based-components. In the *real enterprise* data evolve according with primary process (object instances are parts, machines, human resources, activities like physical transformations), and in the *virtual enterprise* data evolve according with improvement process (objects are the activity models, resource models, etc). Both mappings and their application are illustrated in the chapter on ontology and enterprise modeling.

This leads to two different layers in the ontology at *particular level*, the first one is the *renewing enterprise*, the second one is the *producing enterprise*. Both refer to a common kernel ontology (PSIM-Ontology) and are expressed in the partial level Reference Language. The particular level extension that will support improvement tasks is called the management process (the PSIM procedure for the enterprise), and the particular level extension that will support operations is called the enterprise primary process model.

The Navigator interacts with the ontology-based components to provide the end user the required support functionalities, according with PSIM objectives, as defined by PSIM Procedure. The Navigator follows standardized paths to access PSIM procedures related to activities a worker has to perform and the ontology enables Navigator functionalities to access company data in a standardized way. Navigating the links from the PSIM procedure, the Navigator can reach each specific Action Procedure and start the tools, with the right data and in the right sequence. Being aware of who is operating, the Navigator is, then, able to reach, from the worker behavioral model, the right user interface to be provided in starting the tool.

3.2.2.4 The Architectural View

The architectural view defines the way in which each component (ontology, navigator, integration) is mapped on a technological architecture. We abstract from the technological solutions and the commercial tools that have been used, as they change according with specific requirements of Pilot or tool tests. Only the logical architecture of PSIM environment is explained with in reference to Figure 3.1.

The particular level of the ontology, capturing the specific structures (processes, organization, objects) of each Pilot, enables the Navigator to access real company data, both as part of the operations and the management process. Depending on the Pilot, some data may be either directly stored inside the ontology or simply referenced by the ontology itself. Whenever it concerns data that are available in an ERP system, they will be referenced by the ontology through the Integration Systems, that will extract them from the ERP.

The Navigator will provide the required functionalities by searching, following standardized paths, the mapped PSIM procedure for the task a person wants to perform. It will start the predefined tools and use the ontology-based translators to adapt the data to each tool's concept and data structure. Moreover, it will use the term-mapping and suitable user interface to face a specific end user with the appropriate terms for the task at hand.

3.3 Discussion

Pre-project and in-project legacy, regarding development approaches, but also regarding the applications on the market and the tools in actual use at the pilot enterprises, has created the greatest hurdle for implementing and demonstrating an environment, as ambitious as the PSIM environment. It is mainly for legacy-related reasons that during the PSIM project, it turned out to be unfeasible to test the PSIM environment and its architecture in one piece, and at each of the diverse pilot tests.

Around mid-project it was therefore decided to test at each pilot a different challenging aspect of the PSIM environment using the architecture description presented in this paper. In this way, the differences in interest at each of the pilots could be better responded to. Hence, FIAT tested the PSIM procedure and its ability to support the management of change in the design process; Volvo tested the integrator and the ability for the environment to support the exchange of information from their databases to the STSD and Ergo tool; and the Finland Post's test site was modeled using the ontology. Also in the Yamatake test, the ontology was tested in a study on the real-time optimization of changeover processes in PWB assembly lines.

At the time that this paper is written, the lessons learned from these tests, and their impact on the development of the PSIM environment, have not been consolidated yet within the consortium, nor within its exploitation strategy.

One important line of exploitation and dissemination, however, concerns international standardization in the area of enterprise modeling and reference architectures. PSIM members are actively involved in this work. The revision of ENV 40003 which has been prepared jointly by CEN TC310 WG1 and ISO TC 184 SC5 WG1 is currently being submitted to the CEN EN and ISO IS balloting processes under the title "Enterprise Integration – Framework for Enterprise Modeling". Currently also CEN ENV 12204:1996, "Constructs for enterprise modeling" is being revised by the same committees, and CEN ENV 13550 EMEIS: 1999. "Enterprise Model Execution and Integration Services" is due for revision within the near future. For the revision of ENV 40003, the PSIM environment architecture and its tests offer important new illustrations of how to put to practical use this framework. For the ongoing revision of Constructs for Enterprise Modeling, insights gained from the PSIM environment tests have contributed to solving several issues in the standards drafting process, and so is it expected for the forthcoming revision of "Enterprise Model Execution and Integration Services".

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4. Communication Interfaces inside the PSIM Environment

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Abstract. This chapter deals with the communication interfaces existing within the PSIM environment. A general overview is given of the term mapping techniques that have been applied in the interfaces. The definition, description and development of term mapping between the components of the PSIM infrastructure are analyzed and some examples are also presented. This chapter concludes with a description of the communication layer of the PSIM environment.

4.1 Introduction

In the other chapters of this book, the PSIM procedure and the overall PSIM environment have been described. In the chapter concerning the architecture of the PSIM environment the necessity of a reference language is stated. The current chapter presents the communication interfaces within this environment. We introduce the term mapping mechanisms, and explain how it is used to support the communication between the actors of the enterprise and the tools and databases. The actors are involved in the design, redesign, renewal, of the enterprise knowledge and in the execution of the primary process.

Each communication interface is built on the basis of term-mapping. A term-mapping links the content of a glossary with the terms of the reference language. A glossary corresponds to a list of terms used in the expert domain with their definition in natural language. The term-mapping provides the necessary support to the navigator to customize the PSIM-user interface and to enable the navigator to realize the links between tools and external data. The information for realizing these links is stored in the communication layer.

In the following, the role of the communication interfaces, the mechanisms used to built them, and their content are described. Section 2 presents the communication interfaces and their role inside the environment. Section 3 introduces and describes the mechanism of term mapping. Section 4 describes how to build a customized PSIM-user interface manager. We present the method used to collect data terms and the structure we adopt to store the information. This is illustrated by an example. Section 5 presents the communication layer, composed of a set of translators existing between the tools and the reference language. Then, section 6 concludes the chapter and presents some ideas for further development.

4.2 The Communication Interfaces in the Environment

In the PSIM environment, the communication interfaces play two distinct roles. The first role is to support the customization of the user interface according to user's rights. The second role is to manage the translations and in this way to support the exchange of information between the different tools, which are the components of the PSIM environment, and external databases. Figure 4.1 shows the architecture allowing the realization of these roles of linking the PSIM-users, the enterprise databases and the different analysis tools. The navigator, though not explicitly represented in the figure, is the component bringing life into this static presentation. Simplifying, we can say that the navigator is the component, which is handling and activating the arrows connecting the other components.

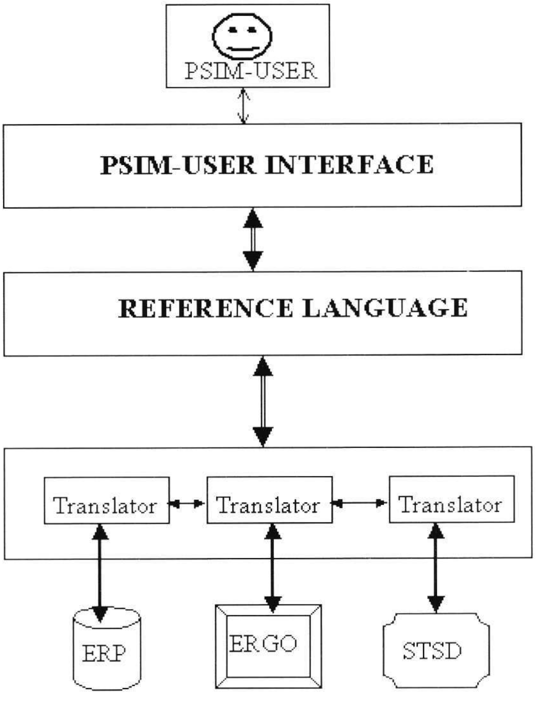

Figure 4.1 The Communication Interfaces in the PSIM Environment

The PSIM environment is composed of three components:

- The *Reference Language*: A central component, which is structured by the PSIM ontology and is presented in Chapter 3,
- A *Customized PSIM-user Interface Manager* allowing the users to access the system in their language (or more precisely the community language they belong to). The term mapping is based on glossaries elaborated by domain experts of a community. Each term of the glossary is mapped to concepts of the reference language,
- A *Communication Layer* allowing, via translators, interaction between different software components such as tools and databases.

The objective of this chapter is the description of the last two components, and particularly the presentation of the techniques used to build them.

The *Customized PSIM-user Interface Manager* allows the sharing of information between different users without forcing them to learn the reference language neither to learn the languages used in other communities. This interface is enacted by the navigator when the user is logged in to the PSIM environment.

The *Communication Layer* manages the exchange of data between tools used in different enterprise analyses, and databases and tools. This exchange of data is realized via a translation mechanism. The translation support consists of providing a semantic communication layer between the different tools.

4.3 Description of the Term Mapping Mechanism

4.3.1 General Description of the Mechanism

Mapping is defined as the mechanism used to convert between structures existing in one component and analogous structures expected by another [1]. The term-mapping is the procedure that manages the exchange of information among experts, among experts and tools, and among tools. In the simplest form a term-mapping expresses the correspondence between a term used in a knowledge domain or by a tool, and the equivalent term from the reference language.

4.3.2 Categories of Term Mapping

Generally, there are two main categories of mapping *'one-to-one'* and *'non-one-to-one'*. In the majority of the cases a term corresponds to a single concept in the reference language models. But for several cases, no one-to-one mapping exist between a domain term and a reference language concept, especially when there are different perspectives linked to the subject of the study. These terms have a common property: they correspond to a composition or a set of reference language concepts.

One-to-One Relationship between Terms and Concepts

About 80% of the terms that are mapped to reference language concepts have a *'one-to-one'* relationship. This one-to-one mapping exists if the term i from the domain B corresponds to a single concept *j* in the reference language. That means that *i* and *j* have the same plain definition.

Non-One-to-One Relationship between Terms and Concepts
Most of the terms with '*non-one-to-one*' relationship have two origins. This relationship results from a difference of granularity in the fundamental element studied in a knowledge domain and the granularity used in the ontology to represent the enterprise. This difference in granularity complicates the term-mapping procedure, to overcome it, the finer concept is introduced into one of the enterprise ontology taxonomies that permits to transform this '*non-one-to-one*' relationship into two '*one-to-one*' relationships.

Another problem arises because different perspectives exist for analyses. Several domains of expertise may use terms that do not represent concepts with existing corresponding terms in the ontology. These terms usually designate a sub-system of the instantiation of the enterprise primary process. In this case, the object of study corresponds to the verification of one or several properties of the sub-system.

STSD Tool		Common Language
Job of Y	→	*The set of organization elements the human resource Y is managed by*

Box 4.1 Example of 'non-one-to-one' relationship

The term *job* as used in socio-technical system design illustrates a '*non-one-to-one*' relationship. The term *job* refers to the sub-system formed by the set of organization elements, which manage a particular human resource. Box 4.1 shows the mapping of the term *job* in the ontology. The term *job* is defined as a collection of activities that can be performed by a precise employee. These activities can be sorted according to their type. Types are related to the speciality the activity has. In the PSIM ontology, this speciality is related to the organizational element managing the activity. Socio-technical experts have agreed that the different type of activities performed by an employee is more important than the list of the activities s/he performs. On the other hand in the model, the activities that an employee can perform are related to the organizational element s/he is managed by and the organizational element characterizes the type of activity it manages. Therefore, the term *job* has to be mapped to the set of organizational elements managing the human resource considered.

4.4 PSIM-User Interface Manager

A general structure of the PSIM-user interface manager is based on the previous description of the term mapping mechanism. The suggested methodology for the development of PSIM-user interface manager has facilitated the design of a well-structured, well-formed, comprehensive and convenient information structure, containing understandable terminology and providing fluent communication among all PSIM users and the tools.

The realization of the interface manager inside of the PSIM project is based on the glossaries provided by domain experts, in our case in ergonomic and socio-technical science. The starting point is a plain definition for each glossary's term the experts uses in their domain. An equivalent corresponding expression was looked up or constructed in the reference language.

4.4.1 Methodology of Collecting Data

One of the main concerns about the PSIM-user interface manager is the development of a consistent and uniform collection of definitions for all the terms. An extensive participation of people involved in the PSIM procedure and other experts in different areas is required in order to collect and represent available information about terms and design the PSIM-user interface manager entries. Generally it is a complex collaborative activity where participants can input, comment, refine and vote for the items that have to be included and their definitions.

The proposed methodology was not just based on human factors and their purposes. The algorithm used consisted of the following steps:

I. *Concept domain categorization*: to identify from which domains concepts will be extracted and included in the glossary (Ergotool environment, STSDtool environment, logistics, navigation, etc.),

II. *Initial collection of terms*: from the above mentioned domains and their initial grouping and sorting. The terms are alphabetically sorted here,

III. *Identification of necessary and sufficient concepts*: a choice of a reasonable amount of concepts, in order to sufficiently cover each domain, but not to cause cognitive overload and overlap between the several concepts, terms and their definitions,

IV. *Development of the End-User Part*: to collect definitions of the chosen concepts from all available sources, such as dictionaries, user guides, etc. It should be mentioned here that an in-depth and wide-scope knowledge and understanding of the whole enterprise model is required for this step,

V. *Ontology definition of each concept*: Taking under consideration the structure of the PSIM ontology and its taxonomies, generic entities and relationships, it is aimed for here to provide an appropriate definition of each concept understandable from the Navigator and the other tools. In depth understanding of the PSIM ontology is required here,

VI. *Other information*: all other information related to each concept and not fitting to one of the two above mentioned fields (steps IV and V) are presented to the last part of glossary,

VII. *Collecting feedback on the proposed set of terms*: enterprise employees and experts assigned with such a task update the "prospective" definitions, refine additional information, resolve conflicts, add/delete terms. It is proposed that every person involved in this process has a different position in the company. PSIM ontology experts have to provide feedback for the ontology definitions of the concepts,

VIII. *Check of the final glossary*: Expert designers check the final output of the whole development process and comment on it.

4.4.2 Structure of the Term Mapping

The main question that arises is what will be the structure in which to store the information of the term mapping. What information should be available for each concept (term)? The content of the PSIM-user interface manager, based on the existing PSIM-environment, is not restricted and could be expanded. Indeed new tools or domains can be added to the PSIM-environment (N_{th} tool, new expertise domain) or new terms can be introduced in an existing domain in the PSIM-environment. It is pointed out that it is necessary to select a reasonable amount of terms and to display the most important ones to avoid cognitive overload.

Table 4.1 illustrates, how available information and data are provided in four columns. The second column 'link' contains information concerning the origin of the term named in the first column. In this case, the domains using the term, are indicated. Each term may have different definitions (from reference language and plain English point of view) when it is fetched from different domains. This is the case of a term belonging to the *'non-one-to-one'* category of mapping.

The column 'DEF_USER' contains a simple definition in plain language. It is given to support the end-users. The content of the column aims for a kind of vocabulary and provides comprehensive definitions of terms and an in-depth analysis of each term, in such a way that all employees of the enterprise (managers, decision makers, operators, designers, etc.) can understand the meaning no matter which is their position in the company, their general knowledge and experience. If this part of the interface manager is considered from the general PSIM environment point of view, it is said that it is related to the end-user view, as discussed in the previous chapters.

Next to the plain definition of each term, an equivalent definition in terms of the reference language is proposed. In this column (the fourth), the terms are described in accordance with the ontology generic entities (objects, activities, information, human resources, technical resources, etc.) and the generic relations between them (relevance, is involved, etc.).

From the previous discussion it is apparent that each concept can be defined infor-mally and formally. Informal definitions are for end-users, and formal definitions (based on PSIM ontology) are for the Navigator, the PSIM environment architects and the application tool developers.

Finally, other information related to each concept is given in the last column, i.e. enlarged term definitions, including examples, similar terms, terms having broader, narrower, opposite meaning, etc. This could include information such as relations to other terms or synonyms and closely related concepts, thus providing the semantic surrounding ('neighborhood') of the concept and unification and consistency of the terminology used.

Table 4.1 The General Proposed Structure for the Glossary

TERM	LINK	DEF_USER (Plain English)	ONTOLOGY DEFINITION	OTHER
Concept N	*STSD*	*An everyday definition in understandable language for any user*	*Relative meaning (view) of concept in ontology and STSD tool*	
	ERGO		*Relative meaning (view) of concept in ontology and ERGO tool*	
	ERP-OLAP		*Relative meaning (view) of concept in ontology and ERP-OLAP tool*	
	TOOL n		*Relative meaning (view) of concept in ontology and n_{th} Tool*	

4.4.3 A PSIM Example of Term Mapping

The term-mapping procedure is mainly determined by the domain. For instance, Ergonomy studies the human's movements that are realized when an activity is performed. So, in this domain, the concept step is a fundamental element. This is the

Table 4.2 Part of PSIM Glossary with Terms of STSD and ERGO Tools

Concept	Link	User Definition	Ontology Definition	Other
Compensation Possibility	*ERGO*	*Possibility to eliminate the differences between the work load of the several resources (human and technical), and workplaces.*	*An information element related to the PSIM procedure which aims to eliminate the differ-ences between the work load of the several resources.*	
Equipment	*ERGO*	*The set of tools used for handling, mounting, orien-tation and fixation of assem-bly. Thanks to them more efficient assembly, less re-quired leading time, less physical load.*	*The set of technical resources and applications that a regular activity needs to be completed.*	
Process	*STSD*	*A series of transformations during the throughput, by which the inserted element changes in place, shape, measurements, function or other characteristics.*	*One or more sequences of regular production activities linked by routing activities in such a way that the output of each regular activity is the routed input in the next regular activity*	
Delivery time	*STSD*	*The time between placing an order and the delivery of the requested products*	*An information element IA relevant. This information can be known only by running the instantiation of the enterprise model. This information has another one, which indicates the unity of time used.*	

reason why, in the ontology, the concept *step* has been introduced. In this way, it is possible to overcome problems carried by finer granularity, and to ensure that the term-mapping of the ergonomic concepts are of the one-to-one kind.

The socio-technical domain studies transversal facts. That means that they focus on the relationships between the people inside the different processes of the enterprise (primary and secondary), and between technical resources and human resources during the performance of activities. From this feature of the socio-technical science result the majority of terms referring to sets of entities (leading to complex term-mapping).

In the previous subsection was described the proposed structure for information storage. Table 4.2 presents some terms extracted from the ergonomic and STSD glossaries.

4.5 Communication Layer

The communication layer's role is to support the exchange of data between different applications. Indeed, some applications are providing data, which are needed as input for the analyses by other applications. In the following, we concentrate on the realization of the connection for the tools developed inside of the project (the STSD and ERGO tool) with other tools (ERP system for example).

Each of the tools manages its own database following its own logic, using its own ontology [2]. The ontology used in each of the cases is locally defined and reflects the paradigm to which the tools are dedicated. Thus the terms, used by the different tools to describe identical things, are very seldom the same. The role of the Communication Layer is to provide for each tool a 'translator', which will translate (map) the internal tool terms in (with) those defined in a reference language. The use of the reference language allows us to decrease the complexity, in accordance with the number of 'translators' needed to support the communication procedure between all the tools.

In order to realize the connection between tools and external databases, the list of the external data, needed as input to the STSD and ERGO tool, is collected. First, the structure used to store the data and the necessary information, that the system has to provide to the navigator is presented. Then, it is described how the term-mapping is used to support the communication between tools.

4.5.1 Structure

In the communication layer, the data and related information are stored in a table. This table contains all the information needed by the navigator to identify the location and the format of the data to provide to the tool, which needs it. Table 4.3 describes the data structure for storing this information.

Table 4.3 The Structure of the Stored Data

Data name	Format	Definition	Ontological def.	Tool	Input	Output

4.5.2 Application of the Term-Mapping

The simplest case we have encountered is when the two domains term (name of the data) are mapped to the same ontological term. That means that to a term in a language A, a single other term correspond in the reference language, which is translated in a single term in the language B. In this case, the concepts are shared 1:1. The sequence of translation is represented in the Box 4.2.

Term tool *i* ◄──► Term common Language ◄──► Term Tool *j*

Box 4.2 Simple Translation

Sometimes, the difference of viewpoints can lead to a difference of granularity in the concepts manipulated in the analysis. We were confronted to this problem when we tried to translate the term *action* used in ergonomic analysis into a corresponding term in an ERP system and support the exchange of information concerning the associate concept. The ergonomic term *action* corresponds to the notion *step* in the ERP system. This notion *step* in the ERP system does not exist independently of the concept *activity*: it is used in *sequence* to describe the *procedure* of an *activity*. In this case, the ontology has to support this translation. This is the reason why we introduced in the ontology the relationship between the concept *step* with the *activity procedure*. To support the exchange of data in this case the general schema of Box 4.3 is followed.

Term tool i Concept a	◄►	Term Common Language concept a	R1 ──► ◄── R2	Term Common Language concept b	◄►	Term Tool j concept b

Box 4.3 Complex Translation Type 1

In table 4.4 some examples of term-mapping contained in the communication layer are shown. A term-mapping of some ergonomic, STSD and ERP data are described. These term-mappings constitute the bases for the enactment of the translators. The data proposed are exchanged between the different tools; some of them are producing these data, others are only using it.

Table 4.4 Example of Extracted Data from the Communication Layer

Data name	Format	Definition	Ontological def.	Tool	Input	Output
Cycle time	*#sec.*	*Time needed to perform an activity.*	*Information, related to the time needed to perform the activity, that an activity has.*	*ERGO*	X	
Frequency	*#products /time*	*Number of the products produced per unity of time, considering an activity.*	*Information element Frequency an activity has.*	*ERGO*	X	
Working hour per shift	*# hour*	*Number of hours per shift.*	*Information contains in the behavioral model the organization element has.*	*STSD*	X	
Work-out time	*#sec.*	*Duration of an activity or task.*	*Information, related to the time needed to perform the an activity, that an activity has.*	*ERP*		X

4.6 Conclusions

In this chapter, the communication interfaces of the PSIM environment were presented. Firstly, we described the roles of each of these interfaces: the customized PSIM-user manager and the communication layer. Secondly, we presented in detail the term-mapping, the basic mechanism applied in the construction of these interfaces, and the way in which we apply this mechanism to build the two interfaces. We provided for each of these interfaces examples of term-mappings extracted from the existing PSIM-environment interfaces.

Research is ongoing on the further systematization and generalization of the method to establish term-mappings between expert glossaries and the reference language. The results of this research will influence the management of the access to tool-managed external databases.

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5. Ontology and Enterprise Modeling

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Abstract. Ontology has the task to construct the most general theories concerning concrete objects, their being and becoming. Concrete objects such as products, facilities and people do also anchor the processes of an enterprise, both its operations and renewal processes. Whereas several enterprise models have been proposed in the past, none has clarified the interwoveness of operational and renewal processes. This chapter first presents general ontological concepts and relationships. It then constructs enterprise model concepts and relationships as specializations of the general concepts and relationships. The joint use of ontology and enterprise model in the PSIM Project is illustrated, and the compliance of the PSIM ontology with the ENV 40003 Framework for Enterprise Modeling is confirmed.

5.1 Introduction

The PSIM ontology has been developed to meet two objectives: *support of semiosis* for those involved in the assembly operations, and the *resolution of the heterogeneity of digital assets,* i.e. of the schema's according to which, and formats in which, data, models and functions are offered to the users, by software applications.

An enterprise model must support the sharing of information, the capturing of enterprise knowledge, the enterprise knowledge diffusion and creation, and the transversal communication between tools and experts of several disciplines.

5.1.1 The Structure of the Paper

The chapter is organized as follows. First, we present some background information on ontology, semiosis and how they have influenced the development of the PSIM ontology. Next, we present the ontology as a component which structures the enterprise model. The joint use of ontology and enterprise model in the PSIM Project is illustrated, and the compliance of the PSIM ontology with the ENV 40003 Framework for Enterprise Modeling [1] is confirmed. The application of the ontology and the enterprise model is further illustrated in the chapter on the communication interfaces.

5.2 Ontology and Semiosis

5.2.1 Ontology and Knowledge Domains

Bunge ([2], p. 5) describes the task of the ontologist as follows: *"he should recognize, analyze and interrelate those concepts enabling him to produce a unified picture of reality"*, with reality understood as being the concrete world, but not including the concepts that words may designate. Bunge considers the number system, for instance, a purely conceptual system, which therefore cannot be combined with, or interact with material systems. In contrast with logic and mathematics studying the conceptual or ideal objects of the law-abiding kind, ontology joins the natural and social sciences as disciplines concerned with concrete objects. Ontology has the task to construct the most general theories concerning these concrete objects, their being and becoming. In contrast common 'scientific' knowledge domains such as ergonomy, logistics and many others, each define concepts and relationships, and connect them to some area of investigation. Whereas the practitioner of a discipline has a strong awareness of the concrete-world things as the anchors and purposes of the analysis, the heavy conceptual bias of the knowledge engineer or information analyst has given rise to several so-called ontologies which are void of the being and becoming of the object of study. Quite recently Parsons & Wand [3] have criticized the tyranny of classes in information modeling, and reconfirm the instance, as model of Bunge's thing, in a more prominent role.

Focused ontologies have been defined and used in several domains including medicine [4], chemistry [5], and legal knowledge representation [6]. In the area of enterprise modeling, early work that would nowadays be classified under the name enterprise ontology is the REA Accounting Model [7]. Wand & Weber [8] have investigated Bunge's work as a theoretical foundation for understanding the modeling of information systems.

In PSIM we have avoided the 'the tyranny of concepts' in ontology by emphasizing a semiotics approach to the formation and application of knowledge.

5.2.2 The Semiotics Approach to Merging Ontology and Knowledge

The term semiotics was introduced by Charles S. Peirce to mean: "*... an action or influence which is, or involves, a co-operation of three subjects, such as a sign, its object and its interpretant.*" In assembly operations, semiosis is concerned with the use or application of signs, models and data, in general, during the production, engineering and business processes. This semiosis links the goals and (programmed) activities of people and software agents to on the one hand past, actual and future, possible and impossible, states and flows of the physical domain and other hand flows and transformations of signs (structured by means of models) in the information domain.

The Framework for Industrial Semiosis (FIS) [9] enriches the concepts of Peircian semiotics to make them applicable in the context of ICT-enabled industry. The object becomes a member of the physical domain comprising the physical space, time and matter; entities – the objects of Peirce's definition of semiosis – have their lives in the physical domain; three kinds of entities are distinguished:

artifacts, agents, and cells (spatio-temporal units). The sign becomes a member of the cyber-netic domain which by employing signs – as intended in Peirce's definition of semiosis – adds memory, communication, monitoring (including knowledge capture) and control (computations) services to the physical domain.

The interpretant is always involved in one of the activity layers: invention and innovation, improvement, operations or observations. The activity layer in which the interpretant is involved will determine the kind of signs that are used, and the actuality of the physical domain objects. Both Peirce's semiotics and Bunge's ontology emphasize the primacy of the thing and its changes over the more freely definable concepts for describing them.

5.2.3 Ontology and Enterprise Modeling

The PSIM ontology allows PSIM users to anchor knowledge management activities and the concepts used for diverse analyses, in the physical resources, facilities, products and their material transformations. This is in sharp contrast with a good deal of the contemporary research in ontologies. To paraphrase the title of Parsons and Wand's provocative paper: the PSIM ontology emancipates the physical reality of the enterprise – its being and becoming – from the concept based analyses (in the knowledge domains, using classes and relationships, a.o.). Anchoring the ontology in the physical reality of the assembly operations is also justified by the importance of reuse and reworking of past experience and solutions in organizational learning [10].

Other PSIM ontology design decisions follow the agreement that *"The shared nature of these conceptualizations allows people or programs to communicate effectively and supports the development of information systems by building interoperable components that view and manipulate information in a unified, clearly defined and consistent manner"* [11].

Quite a few ontologies do not emphasize Bunge's distinction between things and their changes on the one hand and concepts on the other hand. These ontologies therefore have more fundamental concepts than strictly necessary. Examples are the Enterprise Ontology project [12] and TOVE (Toronto Ontology for Virtual Enterprise [13].

5.2.4 Formal Ontology and Ontology Projection

Depending of the use of the ontology, a more or less formal model is needed. Ontologies have been classified as lightweight ontologies or heavyweight ontologies. A lightweight ontology is employed as a help to organize and standardize information content. It consists of standardized taxonomies, (concept hierarchies and relation hierarchies), concept-relation bipartite graphs which capture the knowledge [14], and eventually rules of how the concepts are used. Within this paper we restrict ourselves to presenting lightweight ontologies and represent these as object models and class diagrams. A heavyweight ontology corresponds to a fully formal description of the shared view using a formal specification language [15] [12]. The extra specifications that would make an heavyweight ontology from the PSIM ontology are relevant from a systems engineering viewpoint, but they are not required to understand the contributions explained in this chapter.

Mechanisms of *ontology projection* have been proposed to build more specific ontologies on the basis of more general ontologies [16]. Often, an ontology can be obtained by the reuse (inclusion) of a set of generic ontologies and a detailed, specialization or extension of them. The use of an *inclusion extension* projection leads to the specification of an ontology as generic as the less generic ontology included. The use of an *inclusion specialization* leads to an ontology less generic than those included.

5.3 Structure of the Model: The PSIM Ontology

The PSIM-ontology is a lightweight enterprise ontology. That means that it corresponds to an enterprise meta-model presented as a set of concepts and relationships taxomonies.

In order to identify these taxonomies, we have used the general enterprise modeling constructs from CIMOSA [17] [18], and reverse engineered to a more abstract model, or meta-model. We distinguish three interrelated fundamental concepts. The concepts are *Activity*, *Object* and *Information*. These concepts are linked to each other by the fundamental relationships: *involved* existing between activity and object, and *relevance* linking each of the three concepts to the fundamental concept information.

- *Activity* captures the notion of a transformation to a thing or change, as Bunge defines it. Within the organisation, change consists of the execution of activities to objects, e.g., by transforming *inputs (objects)* into *outputs (objects)*. This transformation may happen only if some *conditions* are verified. For example: "assembling the complete doors to the body", "planning the work", are activities,
- *Object* corresponds to Bunge's thing. Within the organisation, an object is something, which allows the realization of some Enterprise Activities, when it is available. The main feature of an object is *not being available at anytime* [18]. Doors of a car, drilling machines, software, databases, computer, Carl and Julie, are all examples of objects,
- *Information (element)* is a characteristic of either an *object* or *activity* or *information*, which are used to constrain directly or indirectly the involvement of an *object* in an *activity*. For example, how the enterprise is organised is an information element about the way the responsibilities are distributed among the enterprise. How an activity has to be performed is also an information element. The capabilities necessary to realize an activity are also an information element. Each human resource has a profile, it means the list of their capabilities, and it is an information element also. Bunge's conceptual or ideal objects map to information elements. Information elements therefore also include the properties of the objects, and activities,
- *Relevance*: relevance means 'is related to'. Some Information is related to Objects, other to Activities or to Information (recursively). For example: the

weight of a piece of material and the time needed to run an activity. Or another example: information elements can be used to express the conditions for an object instance to be involved in an instance of activity,

- *Involved*: This relationship is a general one. It represents the fact that an object can be involved in the application of an activity. This involvement can be seen as an input, output or resource for example. Involvement as an output means that the object can be the result of the activity.

Each of the fundamental concepts and relationships is refined, that means that it is specialized into a taxonomy of which the fundamental concept is the root. This specialization has for goal to improve the precision of and to better structure the enterprise model. The result of the refinement of the PSIM ontology is the model presented in Figure 5.1. For the justification of each taxonomy and the definitions of each of the new sub-concepts see [19].

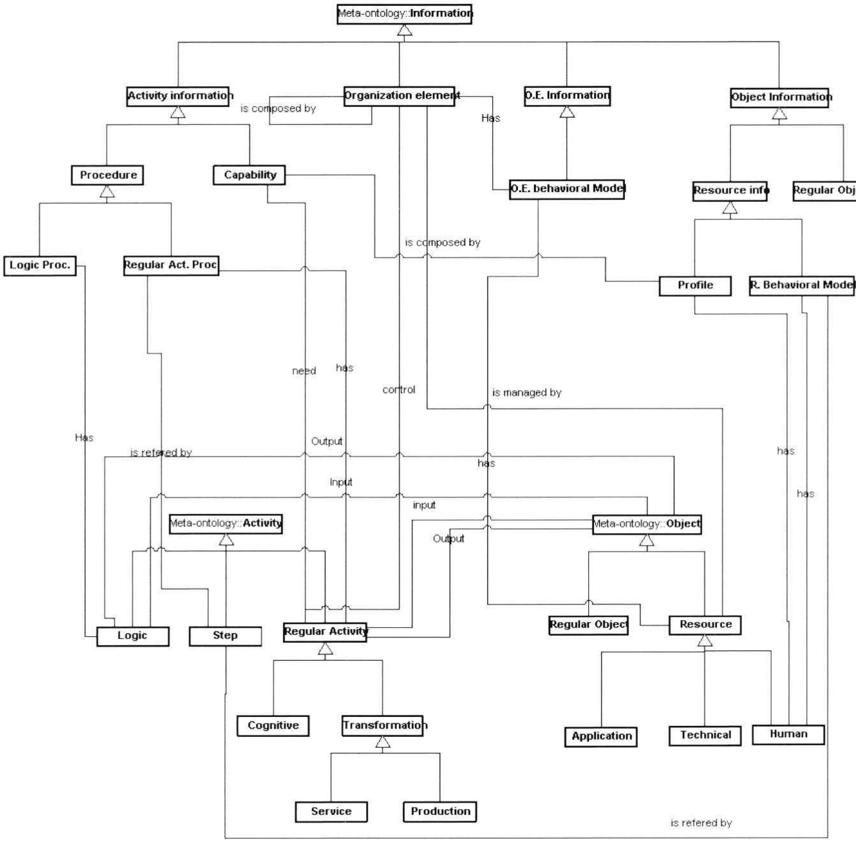


Figure 5.1 PSIM Ontology Using UML Class Diagram

5.4 Enterprise Model

In the PSIM environment, the enterprise model has for role to act as a referent for building support to the communication between tools and different domain experts. Thus the model must be rich enough to support different kinds of analyses for a same object, the primary process of the organization.

Generally, in a manufacturing enterprise, the primary process can be described using only the classes Logic Activity, Step and the Transformation (Regular) Activity. The renewal or the design process consists of instances of the class Cognitive (Regular) Activity performed on a model of the enterprise primary process or part of it. This model and each of its components become Regular Objects. This is a kind of recursion in the ontology. To avoid defining the recursion in the ontology, we choose to separate the model of the primary process from the one linked to the management, renewal and design. In the PSIM environment, this second model is called PSIM procedure.

5.4.1 Primary Process

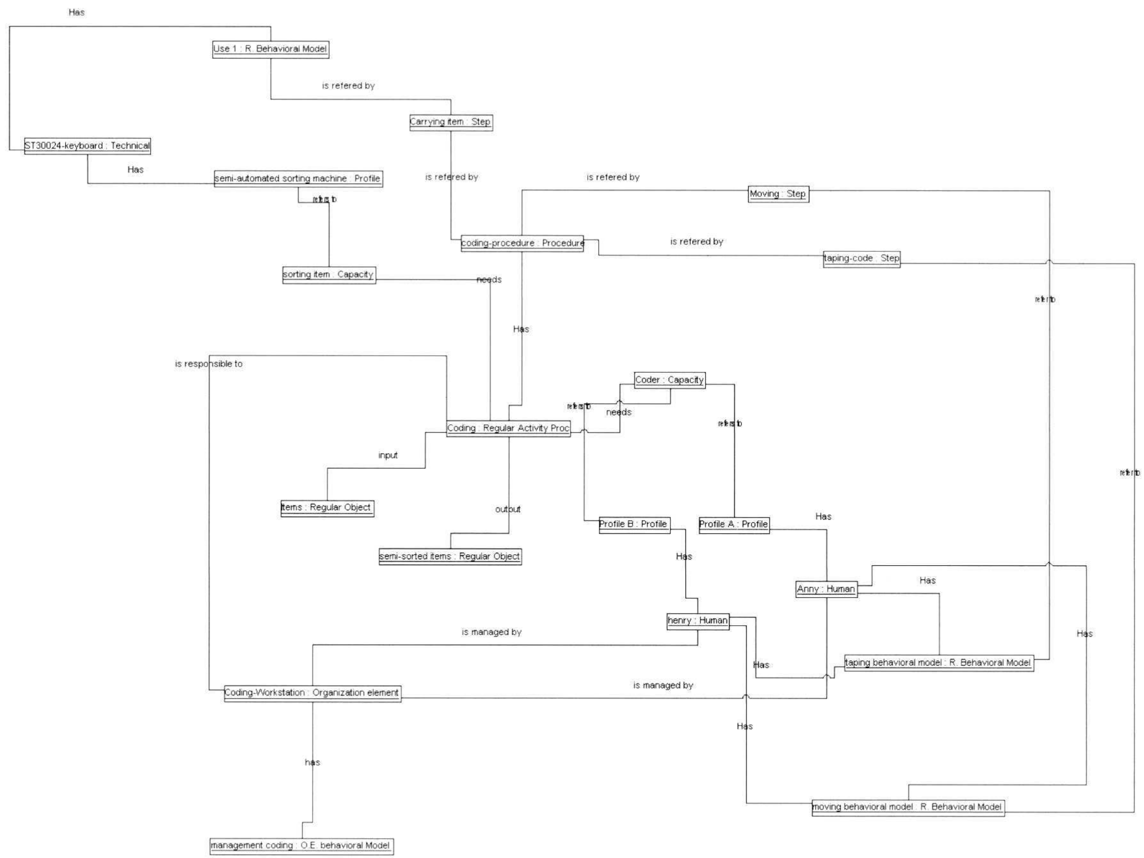
The PSIM ontology, shown in Figure 5.1, allows the description of any enterprise. Indeed, in any enterprise, a *regular activity* has objects as *input* and *output*. It has a *procedure* that shows the sequence of *steps* a *resource* has to follow and the tools (*technical resources*) s/he/it has to use, when this resource performs this regular activity. The *resource* can perform a *regular activity* if and only if its *profile* is composed by the *capabilities* or part of the capabilities needed by the *regular activity*. The *procedure* of a regular activity refers to *steps*. The latter concept is defined in the activity taxonomy. A *logic activity* has also a *procedure*. This procedure describes the conditions linked to the routing of the output of the preceding regular activity into the succeeding regular activity(ies).

The *organization of the enterprise* is described via a set of *organization elements* linked between them. Each organization element can be responsible of other *organization elements*, it manages *resources* and controls *activities*. It has a *behavioral model*, which is a text file explaining the way in which the *organization element* is managing the *resources* and controlling the *activities*.

Figure 5.2 shows the model associated to the coding activity existing at Finland Post.

5.4.2 PSIM Procedure

In the PSIM environment, the process linked to the management of the enterprise knowledge is called the PSIM procedure. This PSIM procedure is, like the primary process, customized to each enterprise. It manages the rules and routines applied throughout the enterprise, in the sense that it makes them easily available to the users. They can consult them quickly on an electronic form.



Figuur 5.2 Modeling of the Coding Activity within the PSIM environment

The PSIM procedure is not only a repository of good practices in the enterprise. It also supports the solving of 'normalized' problems by presenting rules and directives. It also provides routines to accelerate, or better coordinate the activities of improvement, renewal or design. The terms of routine is used here in the meaning proposed by Grant [20]. A routine is an integration mechanism, which corresponds to a *"relatively complex pattern of behavior ... triggered by a relatively small number of initiating signals or choices and functioning as recognizable unit in a relatively automatic fashion"*. Routines allow a high level of simultaneity of individual performance of particular tasks, as well as a highly varied sequence of interaction. They support the analysis of the current practices and the search for improvements, renewal and design. PSIM environment support comprises the enactment of defined routines the enterprise chooses to apply when a need for design or improvement has been detected. These routines are defined in such a way that:

- They manage the cooperation between enterprise members,
- They allow these members to share their ideas, competences and knowledge,
- They guide them in their analysis of the problem and in their empirical search of solutions.

In this way, the PSIM procedure supports the management of the enterprise knowledge. We describe two examples of applying this procedure:

- The diffusion among the employees of available enterprise knowledge,
- The support for change or the updating of the current enterprise knowledge.

The Diffusion of the Available/Captured Knowledge

The diffusion of the good practices applied in the enterprise among the employees is important to ensure the good functioning of the enterprise (see Chapter 3). This diffusion is supported by supplying in an electronic form information related to the way to realize each activity. This electronic form includes the rules, procedures to follow in order to fulfill the activity, and is adapted depending on features of the worker (gender, size, power...). The form can include different data formats (text, figure, film...). Each of these good practices descriptions, independently of their format, is related to the primary process model. They are accessible via the consultation of the behavioral model related to the human resource who is using the system, and the procedure related to activities or steps. The chosen format depends on the availability of (formalized) information inside the enterprise. Examples and more details on this aspect of the procedure are described in [21], and Chapter 7.

The Support in Updating the Enterprise Knowledge Base

The second aspect of the PSIM procedure consists of supporting the evolution of the enterprise knowledge base. This evolution is often the result of a search of improvement of the enterprise's primary process, or of the necessity to adapt it to changes in the business environment (techniques, products, legislation...).

To support the modification of the enterprise knowledge as part of research for improvement, renewal or redesign, the PSIM procedure proposes guidelines on the cooperation among actors involved. These guidelines allow the stakeholders and experts to better coordinate their actions, analyses and exchanges of information. The idea is to introduce by means of the PSIM procedure model a form of organization, which is independent or quasi-independent of the primary process and of the organization of the enterprise. This form of organization is called the fluid team. The composition of a fluid team depends on the activities to be realized. The head of the team is coordinator and selects the members, depending on their knowledge, rules or procedures. The PSIM procedure of the enterprise supplies the coordinator guidelines to define his fluid team, and also information on the way to perform his role. The PSIM procedure also proposes guidelines on how to manage the search of new normalized knowledge. The team is dissolved after its problems have been solved. An illustration of the modeling of this part of the enterprise model is in [21].

5.5 PSIM Ontologies and the Framework for Enterprise Modeling

The PSIM ontologies are compliant with ENV 40003 [1] and CIMOSA [17] as it is demonstrated below using the techniques of ontology projection. The PSIM ontology and enterprise model applies the ENV 40003 dimensions of genericity, generation and model phases.

5.5.1 Dimension Genericity

This dimension has the three levels generic, partial and particular. The Meta-ontology consisting of Activity, Object, and Information is defined at the generic level. The PSIM ontology of Figure 5.1 is at the partial level. It results from projecting the meta-ontology using an 'include-specialisation' for both the enterprise modeling and the ergonomic analysis. From these projected ontologies, we have derived the enterprise model by using an 'inclusion-specialisation' of one or more of the projected ontologies defined previously. The specialisation is done in such a way that the next step is the instanciation of the enterprise model at the particular level.

We do not claim completeness of the ontologies at either level, as our focus has been on supporting different kinds of activities (operations and improvements), rather than on supporting a particular kind of activity for the most general object (product). In fact, at each level more complex ontological concepts could be introduced.

5.5.2 Dimension Generation

The ENV 40003 generation dimension consists of the four essentially different views: the organisation view, the resource view, the information view and the function view. Figure 5.3 shows the connection between these views and the PSIM ontology.

5.5.3 Dimension Enterprise Model Phase

The revision of ENV 40003 defines the enterprise model phases as the manifestations of the life cycle phases of enterprise model development. In the PSIM environment, also the life cycles of the enterprise entities themselves matter. The PSIM procedure has for role to support the user in his search of improvement or design of part of the enterprise s/he working for. This support consists of providing the user the possibility to work on a model of the enterprise. The solution we found was to separate the enacted enterprise model, and the related models supporting the analysis and structuring of the enterprise.

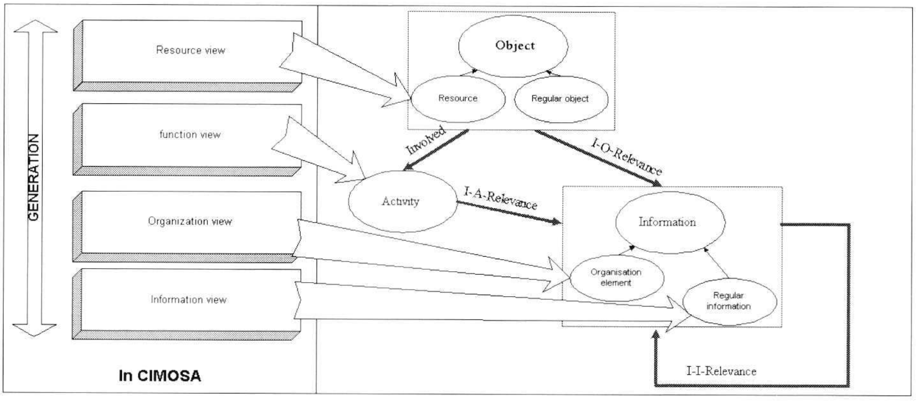


Figure 5.2 ENV 40003 Generation Dimension and the PSIM Ontology

The PSIM procedure model refers to the PSIM ontology and uses (non-enacted) enterprise models described in the common language as input and output. Thus, in the PSIM procedure model, the enterprise model is referred to as an object, which will be modified, analysed, evaluated and potentially changed. Eventually it may be enacted. The enterprise model supports the imagination, creation, simulation, and analysis. The latter activities and their sequences, are often not defined as precisely as in the enacted enterprise model. There is however a growing need to model these activities, as well as their inputs and outputs. The PSIM environment architecture has taken this into account (see Chapter 4).

5.6 Discussion

The PSIM ontology has clarified the interwoveness of operational and renewal processes in the learning enterprise, within the legacy of the international standards in enterprise modeling. The PSIM ontology differs from the majority of other proposed enterprise ontologies by adopting Bunge's primacy of things over concepts, and by analysing the relationships between things and concepts within the tradition of semiotics.

Although the PSIM ontology constructs a very general theory of the concrete things in enterprises, it does this for fairly simple things: the individuals. Hence, one technical challenge for future work: scaling up the ontology from individuals to objects with a state-of-the-art complexity. To this end we have to apply *piecemeal ontological commitment* towards the clarification of 'aggregation' and 'concepts' in addition to the individuals. Solution directions for this problem exist in the theory of product families and generic bills of material.

Another problem concerns the refining of the notion of multi-level semiotic systems. A *meta-semiotic system* is a semiotic system in which another semiotic system is the object. Improvement and renewal are examples of activities that, for a full ontological comprehension, must be analysed in a meta-semiotic system.

Both these problems must be solved in scientific terms before it will be feasible to scale up the PSIM environment services to the depth and scope of the industrial enterprise competing in todays global economy.

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6. Integration of Enterprise Systems to Facilitate Participative DecisionMaking

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Abstract. This chapter describes technical aspects of integrating enterprise information systems. This integration is a prerequisite for effective participative decision-making. The chapter describes lateral integration of a range of enterprise systems with the use of an integration infrastructure and the transformation of data from systems for on-line transactional processing (OLTP) into data for on-line analytical processing (OLAP).

6.1 Introduction

At this moment in time, the theoretical arsenal that drives western manufacturing industry reflects a remarkable paradox. On the one hand the information age has enabled industry to take the full consequences of the fact that they are confronted with buyer markets. Especially the advent of ubiquitous Internet technology has facilitated a much more interactive approach of the market place, unimaginable a decade ago [1] [2]. Against the background of these opportunities companies around the world are made aware of the importance of an efficient individualized approach of the market. Terms like customer intimacy, one-to-one marketing and servitization feature prominently in the idiom of leading consultancies and corporate visionaries [3] [4]. The view on the human individual in the demand side of our economy is increasingly determined by sophistication, attention for variety, strive for uniqueness and individualization [5] [6] [7] [8].

Especially against the background of this last fact it is remarkable that the view on the human individual in the supply side of the economy is still almost exclusively Fordist and unrefined [9]. Whereas the 'customer' is more and more moving to center stage in modern manufacturing thought and brought out in full-colour, the 'worker' remains a flat-character, an anonymous entity, doomed to play only a subservient role in technocratic schemes. The developments in the demand side of the economy puts significant stress on manufacturers in terms of e.g. time-to-market, product variety and quality. But industry seeks to confront these challenges primarily through advances in (traditional) capital, by installing more powerful hardware and software technology. Compared to the attention for technology, the appreciation for the role of human intellectual capital in manufacturing operations has only been marginal, while it is the key to manufacturing strategies that offer more flexibility and better performance [10] [11].

Achieving this however requires that assembly workers are given more status information about their work environment than they normally get, at least during dedicated (re)design sessions. This chapter will describe how the state-of-the-art in information technology can help to leverage initiatives for improvement from assembly workers. More particularly it will address the following two challenges:

1. Turning the crazy quilt of information systems in the typical enterprise into one integrated, consistent and coherent source of information,
2. Making it possible to search for information in this resource in a flexible and ad-hoc manner, as opposed to a rigorous pre-defined one.

These two challenges will be addressed in section 3 and 4 respectively. Section 2 is devoted to a brief historical overview of integration of enterprise information systems. Conclusions are drawn in section 5.

6.2 The Evolution of Enterprise Systems Integration

In the 1970s, most automation in enterprise information processing took place with homegrown systems representing functional silos. These systems turned out to be too inflexible to deal with business change and complex and costly to maintain. More inherently integrated standard software systems, e.g. those for Enterprise Resource Planning (ERP) started to replace the homegrown ones in the 1980s. They combined functionality for several functional domains (shop floor control, warehousing, finance, HR) in one software product [12]. Because they were designed as a monolithic application they provided little opportunity to integrate with systems for remaining areas [13].

To support particular business functions in more depth with richer and more specific functionality, ERP systems were extended in the 1990s with bolt-on applications, such as those for customer relationship management (CRM) systems, warehouse management systems (WMS), advanced planning and scheduling (APS) applications, and transport management systems (TMS). Integrations between those applications and ERP systems were either provided out-of-the-box or were custom built, but usually through static point-to-point connections, sometimes with the use of connectivity tools. As a result many companies currently find themselves caught in a spider web of systems, technologies and interfaces, which is increasingly hard to manage and maintain and incapable of adjusting to the requirements of today's dynamic business environment [14].

Nonetheless in the past five years the state-of-the-art in system integration has evolved from batch file transfer and custom-built interfaces to a higher level of sophistication based on middleware products and standards. Application vendors have started to open up their applications through XML and standard, application-level APIs. Middleware vendors have emerged to provide off-the-shelf tools to connect applications. These so-called Enterprise Application Integration (EAI) solutions provide tools for application connectivity, message transport, data mapping, and so on. Tools emerged to support loose coupling of applications through message-based or data-driven architectures, also termed peer-to-peer architectures. Internet communication models are inherently peer-to-peer due to high latency, message-based communication and standardization of message definitions (such as RosettaNet and OAG).

Whereas EAI solutions used to focus on intranet environments, the scope of the integration problem has reached beyond the enterprise boundaries. With the rapid introduction of business-to-business electronic commerce using Internet, integration of systems across companies has become a challenge as well [15] [16]. As a result EAI vendors extend their offering to cover B2B integration capabilities and support for emerging communication standards as well. Resulting characteristics of advanced integration tools are the ability to support dynamic integration with rule based routing and process control components to initiate processes based on business process models.

A single tool is a far cry from what is sufficient to confront the variety of integration challenges that the world of practice can produce at this moment in time. Instead an integration infrastructure is needed: a combination of tools that together offer a range of features and can support different types of integration. Part of the research in PSIM was devoted to outlining the features of such an integration infrastructure. These features will be discussed in more detail in the next section.

6.3 Features of the Integration Infrastructure

An integration infrastructure should offer enterprises four technology features. The first one is platform independence. Applications have been built on and for various platforms. The integration infrastructure is to provide platform independence, hence facilitating cross-platform communication between systems.

Similarly it should offer language independence as a second feature. The infrastructure should be able to deal with 50 years of programming languages evolution and the resulting variety that especially larger organizations show in the nature of the programs they use.

Reliability of the integrations built should be a third feature of the infrastructure. After all, many applications will depend on them. This reliability includes a relative performance independence for load extension, also known as scalability.

Finally the integration infrastructure should be able to accommodate change. It is likely that extensions will be needed, both as new applications and new services that are built inside and on top of the integration infrastructure.

In addition to these technical features other features are important, with a more functional nature. The first one is related to the ability to create peer-to-peer integrations. Often integrations were built with the assumption that one system would only act as a server, responding to requests of remotely integrated clients. In addition it should be possible to create a situation where equal services are provided to all connected (enterprise) applications. In turn, this should allow the applications to treat each other as peers.

Secondly, applications can be connected through a dedicated link in a 1:1 fashion. However, in a situation of multiple applications it is more efficient to secure their integration through connections with the infrastructure they share, e.g. a broker.

Thirdly, both push and pull mechanisms should be supported. In a pure event-based environment, a request or update is being pushed out or published by the initiating application. The event can be a remote procedure call (RPC) to a specific server application, or it can be an open publication to which other applications can subscribe. Pulling implies that the integration infrastructure is leading rather than the individual applications. It is usually time-triggered.

Furthermore, the integration infrastructure should be able to support both tight, synchronous and loose, asynchronous integration. It should also be able to handle integration for both batch and real-time processes

It should support integration through a hub-spoke set-up in addition to point-to-point. Point-to-point means that the client and server application are fully aware of each other, without an abstraction layer in between. It usually implies that the client application is modified to suit the server application, and renders the integration proprietary to the combination of the two applications. The hub-spoke model introduces an abstraction layer or common object model that each application can plug into. This way, not only a connection can be reused across integrations, but also the mapping of the application model into the common object model. The hub-spoke model gives an exponential increase in integration efficiency, and makes integrations much more flexible, since they can more easily be added or replaced without affecting the overall environment.

A final features was already introduced at the end of the previous section. In a statically integrated runtime environment, integrations have been compiled or configured in such a way that they have a fixed communication line. Little notion is given to the fact that the business context is usually more dynamic than that. Imagine a multi-site environment in which each site has its own ERP system, but only one web store front exists for all customer orders to the company. Depending on the items ordered, the geography of the customer and the availability of inventory, the most suitable production or distribution site is being assigned to fulfill the order. Depending on the outcome, the order needs to be routed to a different ERP application (instance). A routing component is needed to add dynamic behavior to an integration based on business rules and conditions, which are evaluated against the content or properties of a message. The values of the properties determine the destination of the message and the subsequent process flow. The integration infrastructure should be able to support this type of scenario.

6.4 Analytical Processing of Data in Integrated Systems

The enterprise systems mentioned above are built for on-line transactional processing (OLTP). When integrated they can already be much more valuable than when used as stand-alone, but their output is largely produced along the lines of predefined formats, e.g. for weekly reports. Ad-hoc questioning of the systems for one-of problems leads to an unacceptable decrease of their performance. Thus, historically the costs and the amount of effort required to implement a quality decision-support solution based on the current transactional systems usually was too high, especially for smaller and midsize enterprises. For this reason very few enterprises could take full advantage of the nuggets of wisdom contained in their systems. They often lacked the answers to critical business questions, while the data in the enterprise systems – when further refined – could turn into the kind of enterprise intelligence that provides valuable guidance in the decision-making process.

For this reason major vendors of enterprise systems have been increasingly embracing On Line Analytical Processing (OLAP) technology, that provides a high-level aggregated view of data. Although OLAP tools were originally deployed with the traditional image in mind of the single manager at the top of an organizational pyramid, who has to process large volumes of aggregated data, they can of course be used equally well in a setting for participative decision making by others in the company. Based on this idea Baan built an OLAP-based business intelligence framework as part of the PSIM project, that could support flexible data retrieval and decision making based on the guidelines from the PSIM procedure.

Such a business intelligence framework becomes especially powerful if data from several enterprise systems can be combined for analysis. Therefore, a critical feature of a successful enterprise intelligence solution is the ability to translate cryptic, raw transactional data from various sources into consistent, easy-to-use business information. The data from the source systems have to be extracted, transformed and loaded (ETL) into a data warehouse. To automate this process, software code has to be written which executes the ETL sequence on a regular basis. The prototype developed in PSIM has an ETL modeler, which makes it possible to have this code generated without programming. When designing an ETL sequence, no attention is required for technical details concerning the code generation. Thus, non-programmers can still indicate which data they want to use for their analysis in near real-time. Naturally, this significantly enhances the flexibility and quality of the decision making of non-ICT experts.

For subsequent storage of the data in a data warehouse and accessing it later on several commercial products are already available. The transformed data is organized in cubes. The OLAP servers for data access usually support flexible modeling of these cubes with a dedicated easy-to-use cube editor.

As a next step in this process, an OLAP client offers the ability to analyze the data. It is possible to add formulas, filters, graphs, and so on, to the data. It can provide users with deeper insight about trends, causes of events, exceptional situations, and other interesting facts.

As such, this sequence of activities requires the user of the tools to known exactly which data is available in the enterprise systems, where they reside, how they should be combined to lead to meaningful metrics, and which values of these metrics should trigger intervention. Especially given the significant size of the enterprise systems that act as the data source this is not automatically the case. For this reason templates have been developed in addition to the generic functionality discussed above. Each template focuses on a specific business area, e.g. manufacturing, finance or procurement. The templates are based on knowledge of best practices and critical success factors and e.g. contain meaningful metrics for certain domains. They make it possible to go through the steps from extraction to production of crucial information almost automatically. For a specific set of enterprise systems the data extraction can be done without ETL modeling intervention from the user, because the templates exploit the familiarity with the structure of these systems.

Although at first a template may sound as something of a straightjacket in a setting for random questioning, it can give guidance to groups and help them to quickly develop a common understanding about the main issues in a certain domain. It will focus them on the metrics that reflect key performance aspects and develop their understanding for how these are influenced by possible interventions. Of course, extra analysis in addition to what is offered by the template is always possible. Over time templates for additional functional areas will be added to the ones currently available.

6.5 Conclusions

To survive industry should effectuate a much more productive interaction between its well-educated workers and powerful, integrated information systems. The intellectual capital of the assembly workforce is growing, but at the same time it becomes harder for people to initiate meaningful interventions on the shop floor, when they do not have profound access to the enterprise systems that increasingly suck up detailed status information about their plant. Eventually providing easy and flexible access to coherent and comprehensive information for a participative decision making situation requires the availability of an infrastructure for enterprise application integration and, in more or less orthogonal addition, a business intelligence framework, based on OLAP.

Of course this technical core does not suffice to create an atmosphere of successful participative decision making. Expertise about group behaviour management and socio-technical design recommendations such as those in the PSIM-procedure have to embed the technology and make sure it is used in a meaningful way. Indeed, the interdisciplinary intervention needed to integrate participative decision making into the daily routine of executing manufacturing operations is a far from trivial thing. But the PSIM project brought its feasibility one step closer and the state-of-the art of ICT is sufficiently promising to support similar initiatives at an industrial scale.

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7. PSIM Procedure and Navigator

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Abstract. To lead the PSIM users to the tool or combination of tools that address their specific problem situation (Ergonomic/Sociotechnical tool or other tools that are supported by PSIM), a well structured, yet flexible, procedure is necessary. This procedure has to take the interrelations between the different tools into consideration. Therefore, it is firstly necessary that the PSIM user has a guideline that can be followed to use the (PSIM) tools without needing to understand the underlying structure. The *PSIM Procedure* provides such a guideline. Secondly, to be able to relate the IT developed prototypes of the PSIM tools to the company specific IT tools a software version of the PSIM Procedure is needed. This task is addressed through the development of the Navigator: an IT environment that serves as a guide, leading the PSIM user to the right tool or module. This chapter describes various aspects of the PSIM Procedure and its steps. The chapter also describes the software version of this PSIM Procedure, *the Navigator*.

7.1 Introduction

A written PSIM Procedure is essential to be able to understand, how the different tools of PSIM are related and how the PSIM tools will be used in a participative way. This procedure should consider the end-user requirements, sociotechnical aspects to support participative use and the design of human-computer interaction processes. The PSIM Procedure aims to fulfil a moderating function between the PSIM users and the PSIM Environment (consisting of several tools like the Ergonomic/Sociotechnical tool). Therefore, it is necessary to develop a PSIM Environment that integrates the vision and the results of several tools, each aimed to provide specific answers to specific needs. Besides this, the PSIM Environment enables choices and decisions that are optimised against the whole enterprise context and coherent with different points of view. To guide the PSIM users in an attractive and participative way trough the steps of the PSIM Procedure a software version of this procedure was developed: the Navigator. In this chapter we describe the PSIM Procedure and the Navigator and how they are part of the PSIM Environment.

In this chapter the PSIM Procedure is described by looking at the role of the PSIM Procedure in PSIM (7.2.1), the PSIM application in an enterprise (7.2.2), the user-, task-, use- and life-cycle perspectives of PSIM (7.2.3) and the steps of the PSIM Procedure (7.2.4). After that, the PSIM Environment is described in 7.3.1. In 7.3.2 it is described how the Navigator, as a software version of the PSIM Procedure, operates in the PSIM Environment. Finally, this chapter ends with a conclusion in 7.4.

7.2 The PSIM Procedure

7.2.1 The Role of the PSIM Procedure in PSIM

The PSIM Procedure is one part of the PSIM Environment (see chapter 1 and 4) and helps the PSIM users to use PSIM in a way that is coherent, logical and easy to understand. Furthermore it is important to have a clear procedure to be able to keep the use of PSIM simple for the users. Therefore, the PSIM Procedure provides the user interface between the PSIM user and the underlying elements of the PSIM architecture.

This PSIM architecture consists of the *PSIM Procedure model* and the *enterprise model*. The PSIM Procedure model shows how the steps of the procedure are related to each other; the management of the user interfaces, setting up a PSIM user group and guiding the users to the relevant tool or tools. Because PSIM must be usable in different types of enterprises it is only possible to have a generic enterprise model, that will be instantiated for each specific enterprise that uses PSIM. This enterprise model describes how an enterprise is organised in terms of the processes that take place, organisational structure, the employees and their tasks etc.

The PSIM architecture integrates tools like the Ergonomic/Sociotechnical tool (E/S tool) as well as in-company systems, like ERP systems and other tools. To make this integration possible a 'language' is used that is shared by all elements of the PSIM architecture: the *Ontology* (see Chapters 3 and 5).

To be able to extract data that are specific for an enterprise (e.g. information about the processes and the employees of enterprise X), the PSIM Procedure model uses a common language so that the data it extracts and manipulates from other tools can be used. To extract these data from other tools a communication layer is used. This communication layer consists of a set of translators that translate the data from the different tools into (for the Navigator) comprehensible terms and vice versa. The Navigator then uses these terms to provide a user interface for the PSIM users to lead them through the steps of the PSIM Procedure.

This paragraph gives a rather technical description of how the PSIM Procedure is integrated in the PSIM Environment. In the next paragraph we describe how the PSIM Procedure can be applied in practice.

7.2.2 The PSIM Application in an Enterprise

PSIM is aimed at manufacturing enterprise use. The reason or trigger for PSIM use is likely to be a work related problem within the enterprise, detected by an individual or group of employees. When an employee has a problem he/she must be aware that PSIM can help to solve that problem. To make this possible all employees are informed about the existence and the possibilities of PSIM. In each enterprise that uses PSIM, an organisational unit, e.g. a product-/process develop-ment unit, is responsible for this introduction, as well as for the facilitation and stimulation of the use and maintenance of PSIM.

Besides this, the use of PSIM must harmonise the daily activities of an enterprise. Because PSIM aims at organisational renewal, it is important that it supports enterprise renewal activities. Renewal often includes radical changes and these activities are often organised in enterprise-wide projects where several parties are involved. The PSIM projects have to match the enterprise projects, which can be done by using a PSIM project in a specific phase of an enterprise project. Consequently, PSIM can and should be used all through the development of a new production process, starting with the idea generation phase.

Finally, PSIM must optimally use the available data in an enterprise. Therefore in PSIM the use of different tools is integrated. By coupling tools like the E/S tool via the *Ontology* (providing an overall framework) and the *Navigator* (extracting the right data) to the Enterprise Data Base of an ERP system the use of ERP data is made possible. With help of an integrated ERP system, it is possible to use up-to-date enterprise data in tools that are part of the *PSIM Environment*. The total PSIM Environment consists of a PSIM Procedure and tools that this procedure supports with help of the Ontology (see chapter 3 and 5) and the Navigator (see 7.3.2).

7.2.3 The User-, Task-, Use- and Life-Cycle Perspectives of PSIM

The PSIM Procedure offers simple guidelines for the PSIM users on how to use PSIM. To be able to construct these guidelines, it is important to analyse the use of PSIM from different perspectives:

1. *User perspective (who uses PSIM?): the user and the roles this individual plays in using PSIM (including multiple roles).*

This perspective relates to the user and the role this individual plays when using PSIM (can include multiple roles; e.g. operator, decision-maker or designer). The participative aspects of PSIM emphasise cooperation (with the support of PSIM) between several people that have different roles, independent of their position in the company hierarchy. However, it is also possible for the company to restrict the freedom of PSIM use for certain employees. Besides the participative use, parts of

PSIM and its integrated tools can be utilised individually (e.g. for learning about a specific topic or testing a solution).

2. *Task perspective (why is PSIM used?): the task the user of PSIM performs.*

The PSIM Procedure guides the user when initiating and performing work tasks. The main tasks are (re)design & reengineering, problem solving, learning and decision making. By supporting the user throughout each task, the PSIM Procedure enhances the integral manufacturing enterprise renewal defined by the PSIM project.

3. *Use perspective (how is PSIM used?): how is the use of PSIM organised and related to the normal every-day-work that has to be done?*

One characteristic is that PSIM can be used when the employees want to. This can be when an individual employee has some spare time during the normal work or in specially organised group sessions during which employees work with the PSIM tool in a participative way.

4. *Lifecycle perspective: at what point in the lifecycle (of a product or process) is PSIM used?*

PSIM can be used in different stages of product- or process development (or in different phases of enterprise projects). At what point does the user enter the (re-) development process, what previous information can be accessed, etc.? How and when PSIM is used also depends on the type of enterprise as well as what types of projects and work processes that specific enterprise utilises.

7.2.4 The Steps of the PSIM Procedure

The PSIM Procedure consists of a number of steps. These steps lead the PSIM user to the right tools or modules of these tools, depending on the role of the PSIM user (the user perspective) and what (s)he wants to use PSIM for (task perspective). Based on this information the right tool is selected by PSIM. We describe below the steps necessary for the PSIM user to enter the right tool.

Step 1: User identification (*Who are you?*)
In this step the user is identified by filling in a combination of name and password. Coupled to this combination are characteristics that are specific for an individual like role, department, function, e-mail address and phone number.

Step 2: Selection of a PSIM option (*What do you want to do?*)
After entering the PSIM Environment, the PSIM user can choose from several options regarding what (s)he can do with the PSIM:

a. "I want to work on a running project."

A specific tool will be entered (e.g. E/S tool) in a specific place. The PSIM user is led to the step where (s)he, with the other project members, stopped the last time they used the tool.

b. "I want to see information of finished PSIM projects."
The PSIM user can select a PSIM project of which he/she wants to know something. The information regarding these PSIM projects is stored so that it can be abstracted immediately. Moreover, this information is up-to-date.

c. "I want to see intermediate results of running PSIM projects."
The PSIM user can select a project of which (s)he wants to know more. The information of these projects is stored so that it can be abstracted immediately. This information is up-to-date because all information regarding the progress of a current PSIM project is stored after the PSIM users stopped (temporarily) working on the project.

d. "I have a problem that I want to solve."
See step 3 for a detailed description of this option.

e. "I want to learn something about a specific topic."
The PSIM user enters a specific tool (e.g. E/S tool) in a specific place. The PSIM user is led to that part of a module where information is given about the topic chosen by him/her.

f. "I want to enter a problem or question to analyse it with other colleagues."
The PSIM user can fill in a problem or see if other employees have filled in a similar problem. If there are more employees who have the same problem, the tool suggests to start a dialogue on how to solve it, before actually using a tool.

Step 3: Description of the steps of "D" (I have a problem that I want to solve)
Option "D" consists of a number of steps:

Step D1: "What is your problem?"
The PSIM user has to fill in a name (s)he wants to give to the PSIM project and an own description of his/her problem in a few sentences.

Step D2: "What objectives do you want to reach?"
The PSIM user sees a list of objectives that can be reached by the available modules. Then the PSIM user selects the objectives he/she considers as most relevant for the problem. The PSIM tool relates the modules to the selected objectives and the relevant modules are shown. If there are more than one, a module has to be selected to start with. But, before that is done the PSIM user has to collect people to work with him/her on making this selection (step D3). Furthermore, a PSIM coordinator who coordinates the tool use has to be selected (step D4).

Step D3: "Contacting other problem-owners."
The PSIM user now knows what tools he/she can use to solve the problems. If the PSIM user already knows other people who have the same problem he/she can contact them directly. Otherwise the PSIM user has to go on to step D4.

Step D4: "Selecting the PSIM coordinator."
The main roles of the PSIM coordinator can be summarised as: (a) the role of an ombudsman who helps the PSIM user group to get what they need; and (b) the role of an organiser and facilitator who coaches the PSIM user group during the work for one or more tools. The PSIM user can select an available coordinator from a list that has been made at the initial use of PSIM.

Step D5: "Defining the PSIM user group and the relevant work system."
To define the user group the PSIM users have to answer some questions regarding the employees related to the problems. Based on the answers a list is made of people

that have to be involved in the further tool use. Based on this selection the PSIM user group is formed. The PSIM coordinator has a leading role in contacting the team members.

Step D6: "The right tool for your problem."

Now that the PSIM user group is formed, it is important that every member agrees with the defined objective. Therefore in a kick-off meeting the list of objectives is shown again, and the PSIM user group members decide together whether they want to change the initially chosen objective or not. The chosen objective forms the basis for the selection of the relevant tools. The relevant modules are shown and by clicking on one, it can be selected and entered.

After this description of the main elements of the PSIM Procedure, we now describe the Navigator and how it is related to the PSIM Environment and to the PSIM Procedure.

7.3 The Navigator

7.3.1 The PSIM Environment

In the PSIM project a participative approach is supported. This means that a certain number of workers, physically gathered round a table or virtually working as a group by means of IT, should be able to give each other visibility on problems and possible solutions, to share data and exchange information. An environment enabling such a work approach will, therefore, represent a powerful support to the management and optimisation of operative realities, by supporting decisions and enabling checking alternative operative solutions from all points of view against the final global objective. Nevertheless, such an environment, to support Integral Enterprise Renewal, has to be extended to concepts coming from the Ergonomic and Sociotechnical points of view, like usability, user-friendliness, safety and life quality. The PSIM Environment has, therefore been designed to be:

- Easy to adapt to enterprise specific technologies, that is to integrate, whenever it is possible, those tools the company uses,
- Easy to adapt to different work environments, to retrieve and integrate different experiences and competences,
- Transparent against Enterprise Information Systems: after its set-up, the PSIM Environment will look at Enterprise Data and Processes with a structured view, in accordance with a common methodology providing a reference framework to map the Enterprise, becoming a cross reference middle-ware.

7.3.2 The Navigator in the PSIM Environment

Before describing in detail its components, it is necessary to give an overview of the whole environment, specifying functional integration and interactions between Ontology and Navigator (see also chapter 3 and 5). Moreover, a clear understanding has to be provided on where and how PSIM concepts and objectives are mapped and enacted by the Navigator. We will provide an overall view of how and according to which approach the Navigator will access and provide information and enact support tools in order to satisfy, from a technological, organisational, ergonomic and socio-technical point of view, all the objectives and requirements any actor inside an Enterprise (a worker, a designer, a manager) may have in performing his/her activities.

The Navigator knows, through the Ontology, the way each worker approaches the PSIM Environment, which tools (s)he needs to be supported by and with which user interface. Furthermore it knows which information (s)he will be given and what other support is needed to accomplish the job.

When a *User* introduces himself to PSIM via the Navigator, he/she will be informed of the *tasks* (s)he is allowed and/or required to perform at that moment, according to the *Job* description. The worker, then, chooses which *task* he/she wants to perform and the PSIM Environment will select the *PSIM Procedure* related to the chosen *task*. The Navigator will start, in accordance with the specific *PSIM Procedure*, all suitable tools, in the right sequence. Each *tool* will be fed, by the Navigator, with the information related to the specific *action*, in the specific *task* to be performed by *that user* at that point in time. All these specialised data are found by the Navigator inside the Ontology or provided by the Ontology itself mining them inside either Enterprise Data Bases or Integration Data Base. In principle, each worker, can consider the tasks defined by his job from two different perspectives: an 'operative perspective' as well an 'improvement or renewal perspective'. This means that, in performing his work, an actor may be asked to cover different roles:

- To act as an operator, that is to perform a specific action,
- To act as a decision maker, that is to take operative, organisational and/or technical choices,
- To act as a designer, that is to reengineer and improve the way an action is performed.

Depending on the role the PSIM user has, he/she will be supported by different tools working on different kinds of data, in different work environments:

- When acting as an operator, he/she will operate in the real enterprise environment, supported by tools loaded with run time data,
- When acting as a decision maker, he/she will operate in the virtual enterprise environment, supported by tools loaded with virtual data, corresponding to the present real situation, and use a virtual environment for a what if analysis,
- When acting as a designer, (s)he will operate in the virtual enterprise environment, supported by tools loaded with virtual data, may be corresponding to a present or past real situation, and work in a virtual environment to be able to define and verify several alternative solutions.

In figure 7.1 an overview is given of the steps of the PSIM Procedure that are supported by the Navigator. The figure shows how the Navigator forms the user interface that guides the PSIM users through the steps of the PSIM Procedure.

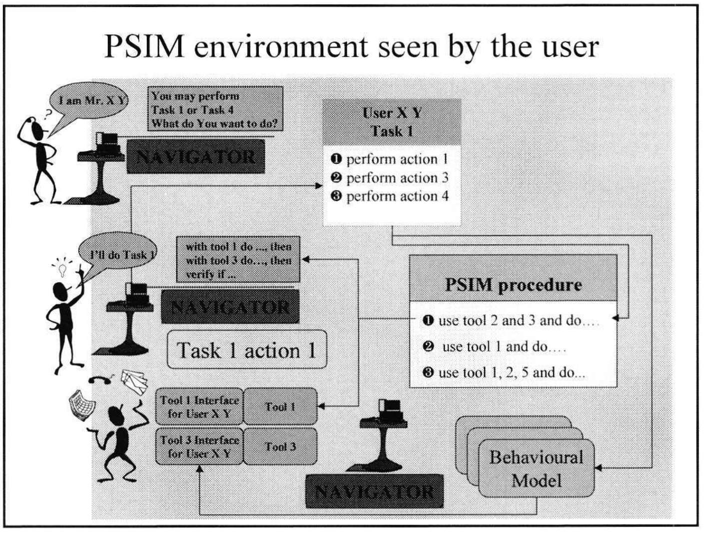

Figure 7.1 The Steps of the PSIM Procedure Supported by the Navigator

7.4 Conclusion

The description of the PSIM Procedure offers an insight in the steps that are needed to lead the PSIM users to the right tools or modules. It also clarifies the interrelationships between several tools and modules of the PSIM Environment. The software version of the PSIM Procedure, embedded in the PSIM Environment, is the Navigator. The Navigator was developed, making use of the opportunities that modern ICT offers and is a clever interface between the enterprise, its processes, data and objectives, and each worker, his job, capabilities, work environment and support tools. It makes data exchange between several tools possible. Besides this, the Navigator provides the PSIM users an easy to use and attractive interface to go through the procedural steps of PSIM and use the available tools in the process of solving problems.

8. The Theoretical Rationale of the STSD Tool

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Abstract. Within the PSIM project the concept for a tool has been developed that supports a continuous and integral improvement of assembly processes (cf. Chapter 10). One part of the tool supports sociotechnical system design (STSD). In this chapter the origins and the core assumptions of STSD are presented together with two STSD methods (KOMPASS and IOR) that have been incorporated in the tool. Generally STSD aims at a joint optimization of human and technology. Whereas KOMPASS provides criteria for task analysis on different design levels (i.e., human-machine function allocation, individual work task, work system task), IOR provides an integral view by focusing on the three aspect systems of work organizations (i.e. production structure, control structure, information structure). It is argued that the former supports analysis and the latter design of work systems.

8.1 The Origins and Core Concepts of Sociotechnical Design Thinking

The history of work system design is often described along three phases, e.g. [1] [2]:

(1) a technical phase at the beginning of the 20th century when the dominant understanding of work systems focused on their technical characteristics, also trying to fit human behavior into the machine metaphor,
(2) a social phase in the middle of the 20th century when social influences on human behavior were stressed resulting in modeling work systems mainly as social systems,
(3) a sociotechnical phase which began in the 1950s and carries on to the present day, characterized by the core assumption that technical and social elements of work systems need to be understood and fitted together for their proper functioning.

Usually, the beginnings of sociotechnical design thinking are dated back to a set of studies undertaken at the Tavistock Institute of Human Relations in London, which were to identify the causes of productivity losses in coal mining in Great Britain after introduction of major technological innovations [3] [4]. Analyzing the work system design before and after the introduction of the new production technologies, the core finding was that crucial characteristics of the organization of the social system which guaranteed its efficient and safe functioning had been lost through fitting a new and in itself inefficient organization to the demands of the technology (cf. [5] [6] for excellent and very detailed descriptions of the development of sociotechnical systems theory). As main indicator for the misfit between organization and technology served the work system's inability to adequately handle internal and external uncertainties, stemming from the coal mining process itself and the system`s environment respectively. More specifically, it was found that small polyvalent self-regulating work groups which were paid based on the total amount of coal hauled by the three shifts responsible for a defined part of the seam had been replaced by highly specialized larger shift groups coordinated by a shift deputy and paid based on the performance of their specific tasks. Lack of direct coordination between tasks affected by a disturbance in the work process due to lack of competence as well as motivation in the individual workers concerned was identified as the main disadvantage of the new system and as main cause of the productivity losses.

From these studies emerged three basic principles of work system design, which can still be found in the many variations of sociotechnical design thinking existing today, cf. e.g. [7]:

(1) Work systems are open systems and as such have to continuously deal with disturbances and variances stemming from internal transformation processes as well as from the system`s environment,
(2) Work systems are comprised of a technical and a social subsystem, which function according to different underlying rules and mechanisms,
(3) Work system design should be aimed at the joint optimization of the social and technical subsystems, with the competent handling of uncertainties as core indicator for having achieved this design objective.

In providing more concrete design solutions, the central concept is that of self-regulating work teams as e.g. described by Trist: *"A socio-technical theory of the efficacy of autonomous work groups is based on the cybernetic concept of self-regulation. The more the key variances can be controlled by the group, the better the results and the higher the member satisfaction. Over a large array of situations, the range of variances controllable by a group is greater than that controllable by individuals separately linked to an external supervisor"* [8: p. 34].

Two important criticisms have frequently be made in relation to the sociotechnical systems approach to work system design: (a) the lack of openness to different design solutions due to the narrow focus on self-regulating work teams as design principle, which hinders truly participative design; (b) the dependence of organizational design on technological choices made prior instead of the proclaimed joint optimization, e.g. [9].

Interestingly, the tendency to take technology as given and try to unilaterally fit organization design to technological characteristics, does not only stem from practical difficulties in influencing technical design decisions, but also has conceptual roots. In early organization theory, technology and work task have frequently be seen as one and the same, with the organization aimed at providing the best conditions for fulfilling the task which itself is inseparably intertwined with the technology used to perform it. A quote from Perrow illustrates this thinking: "First, *technology, or the work done in organizations*, is considered the defining characteristic of organizations. That is, organizations are seen primarily as systems for getting work done, for applying techniques to the problem of altering raw materials – whether the materials be people, symbols or things. (...) Second, this perspective treats technology as an independent variable, and structure – the arrangements among people for getting work done – as a dependent variable" [10: p. 194, italics added]. Only later, conceptions of task and technology have been separated, allowing for reciprocal relationships between organizational and technological design in view of performing a task. Again, a quote from Perrow may illustrate this altered understanding of work system design: "(...) I hope I have suggested that organizational theorists pay attention to the way mere 'things' – equipment, its layout, its ease of operation and maintenance – are shaped by organizational structure and top management interests, and in turn shape operator behavior. The early work on technology and structure, including my own, recognized a one-sided and general connection, but it failed to recognize how structure can affect technology and speculate about the large areas of choice involved in presumably narrow technological decisions, choices that are taken for granted because they are part of a largely unquestioned social construction of reality – one that should be questioned" [11: p. 540].

In the PSIM project a sociotechnical system design tool (STSD tool) supporting analysis and design of work systems has been developed (see Chapter 10). The two sociotechnical approaches incorporated in this tool, namely IOR and KOMPASS as presented in the subsequent sections of this article attempt to avoid the first shortcoming by balancing expert-driven design based on a set of design criteria with openness to design solutions derived through full participation of all individuals affected by the design. The descriptions of the two approaches will give some indication of how this delicate balance can be achieved. The second shortcoming is especially addressed by the KOMPASS method, because in addition to organizational and task design criteria also criteria for the allocation of tasks between humans and technology are formulated, which lead to specific technological requirements instead of taking technology as given.

8.2 Complementary Analysis and Design of Production Tasks in Sociotechnical Systems (KOMPASS)

Within the framework of the sociotechnical systems approach the KOMPASS-method has been developed in Switzerland [12]. The main purpose of the method is to provide operationalized criteria that can be used in a participatory process to analyze, evaluate and design work. What is aimed at is a work design that allows for efficient, safe, and sustainable work processes.

8.2.1 Common System Design Principles

KOMPASS supports organizational and job design with a special focus on automation. It follows a complementary approach, in which humans as well as technology are considered valuable resources. Such a complementary approach differs very much from other principles that are frequently used in the design of automated work systems:

(1) Cost efficiency: Humans and technology are both considered to be cost producing factors only. Tasks are allocated to human or machine according to short-term economic considerations. Costs that are not easily quantifiable (e.g. know-how) are neglected,
(2) Leftover: Technology on the one hand is considered to guarantee for process efficiency and safety. Humans on the other hand are seen as risk factors that are not reliable and therefore cause malfunctions. Tasks are automated as much as possible assigning the human operator just those functions that cannot be automated,
(3) Comparison: Humans and technology are considered to be competitors. Tasks are allocated to the human if he/she supposedly performs it better than the machine and vice versa.

These principles are insufficient for an adequate allocation of tasks between human operators and technology for a number of reasons (cf. [13] for a more detailed review of the task allocation strategies). The main problem is that they do not aim at deliberately creating meaningful jobs for humans or at providing supportive working conditions. In the cost oriented as well as in the leftover principle jobs and working conditions are rather accidentally generated by-products of technical design. The comparison principle is based upon on a quantitative comparison between the ability of humans and technology. This does not only implicate that human and technical abilities are comparable on a quantitative level. It also causes the danger to create jobs which are impossible to perform for humans [14]. This is due to the fact that it is supervisory control over automated processes what is left for the human when processes are automated. But if process control is allocated to the technology because human control abilities are not sufficient, then it can become an unaccomplishable task for the human, to supervise the automated process in real time.

8.2.2 The KOMPASS Criteria for Analysis and Design

Complementary system design aims at avoiding such unbalanced situations. It takes into explicit consideration that human and technical system - based on the differences in strengths and weaknesses of both - can achieve through their interaction a new quality possible neither to human or technical system alone. Hence it focuses on qualitative differences between human and technical potentials. Humans for example are strong in being a creative problem solver regarding ill-defined occurrences, whereas technology can very efficiently handle well-defined problems on the basis of algorithms. But the human requires some preconditions to be able to develop his specific potentials. He needs to have both, the required competencies as well the motivation to deploy these competencies. Complementary system design aims at designing work in a way that provides the human with respective working conditions.

In order to reach a suitable combination of human and technology KOMPASS incorporates operationalized criteria for analysis and design on three levels [12]:

(1) *Human-machine interaction*: The controllability of the technical system by the human formed the core assumption for the development of criteria on this level. That means that automated processes need to be understandable and predictable for the human and he/she must have possibilities to influence them. The criteria are: process transparency, dynamic coupling, decision authority, and flexibility. These criteria base on psychological control theories as well as on system control theories,
(2) *Human work task*: The human – in order to be motivated and empowered to perform his or her part in the human machine interplay – needs a meaningful and challenging task. The criteria on this level are: task completeness, planning and decision making requirements, communication requirements, opportunities for learning and personal development, variety, transparency of work flow, influence over working conditions, and temporal flexibility. These criteria mainly stem from action theory, stressing the importance of hierarchically and sequentially complete tasks for individual competence development and job motivation,
(3) *Work system*: Work structure and processes, distribution of tasks and decision authority among work system members, and the individuals' knowledge and skills should permit the regulation of system variances and disturbances at their source, thereby avoiding their uncontrolled propagation or even preventing their occurrence. The criteria on this level are: task completeness, independence of work system, fit between regulation requirements and regulation opportunities, polyvalence of work system members, autonomy of work groups, and boundary regulation by superiors.

8.2.3 The KOMPASS Design Process

The KOMPASS-method supports participatory design by providing a balance of knowledge on the *how* and *what* of a design process. Thereby especially, normative design assumptions are handled with great care, because they can easily disturb a democratic discussion process severely and create unsurmountable resistance. Therefore the KOMPASS method provides guidelines for a design process to help participants to bring together their own knowledge. The guidelines aim at assisting designers in both, in the explicit reflection of the design approach as well as in the derivation of applicable design requirements according to the principle of complementarity [12]. For that purpose the guidelines support a systematic facilitating of a participative and creative problem solving and decision finding process in interdisciplinary design teams. The aim is not only to work out solutions for the actual design process, but even more to increase both, the design team's ability to apprehend sociotechnical complexity and to bring together individually specialized knowledge. The KOMPASS guidelines support four phases of the design process: (1) project organization; (2) expert analysis of existing work systems; (3) reflection of the design approach for new work systems; and (4) derivation of design requirements.

8.3 Integral Organizational Renewal (IOR)

IOR stands for Integral Organizational Renewal and is a Dutch variant of the sociotechnical approaches that were developed in Western Europe after the Tavistock studies in the fifties. This sociotechnical approach was first introduced in The Netherlands in the early sixties. De Sitter did important theoretical work in the development of Dutch sociotechnics [15] [16]. Inspired by Swedish applications, he developed a design focussed theory for an 'integral' approach to organizational renewal in which the total organization is the object of design. It turned out that the design of tasks and organization could not be separated; the quality of work and the quality of the organization are interrelated [17].

IOR is a cybernetic, open-systems approach that provides a sociotechnical basis for the design of business processes, organizational structures and human work, in order to create a 'dynamically balanced production function'. The approach takes as its starting point the architecture of the actual division of labour. Modern sociotechnical design theory is being used in order to transform this architecture. Moreover a participative redesign strategy called Self-Design by Knowledge Transfer is adopted as part of Integral Organization Renewal. The result of a typical Integral Organizational Renewal implementation process is a flat organization, based on self-managed and decentralised teams [18]. To realise this, IOR uses a specific (re)design process consisting of a number of steps. In the following sections first this (re)design process will be described. Then it will be scrutinised and the holonic point of view on which the IOR approach is based will be described.

8.3.1 The IOR Re-design Process

IOR aims at an integral renewal of organizations; the redesign of current business processes, organizational structures and human work plays an important role in organizational renewal. IOR's ambition is to integrate both work and organizational design with information systems design, with a special emphasis on the creation of parallel subflows in production [19] [20]. In order to facilitate the re-design process, IOR uses in its implementation trajectory a unique decomposition in aspect-systems (i.e. production structure, control structure and information structure).

For this IOR implementation trajectory a stepwise re-design method is used, consisting of the following steps (cf. figure 1):

(1) (Re)design the *production structure* aspect system top-down: parallellisation of order flows at macro level, segmentation of order flows at meso level and the formation of self managing teams at micro level. De Sitter [16] defines the production structure as the architecture of the grouping and coupling of executive function in relation to order flows (e.g. selling, designing, preparing, manufacturing and assembling tables and chairs or producing the tables and chairs in two independent production flows, are two different examples of production structures for the same production process),

(2) (Re)design the *control structure* aspect system bottom-up: control loops for the self managing teams are allocated at micro level. All control loops that cannot be allocated at this level are allocated at the meso and macro level of the control structure. De Sitter [16] defines the control structure as the architecture of the grouping and the coupling of control loops. The processes or functions in the production structure are to be 'controlled', which implies that the production structure determines the degrees of freedom of the control structure (in the table/chair example: depending on what production structure you choose, the control structure varies),

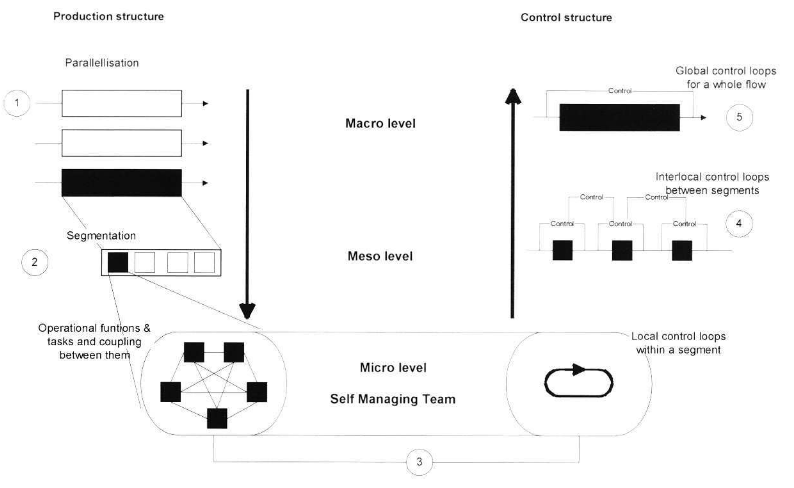

Figure 8.1 The Stepwise Redesign Method of IOR [20]

(3) Redesign of both production and control structure precedes the redesign of the *information structure* and process technology. The design of the production structure forms the basis for the control structure which is the basis for the information structure. The contents and form of the required information and the way this information is stored, processes and transferred, is what De Sitter [16] calls the information structure.

Furthermore IOR approach is based upon a holonic point of view focussing on an organization or department as an integral whole. We now describe the consequences of this holonic point of view for the IOR approach.

8.3.2 Holonic Approach

In the IOR approach a work system (e.g. an organization or a department) is considered as a whole consisting of interdependent parts: aspect systems. As IOR focuses on aspect systems, it is thus based on a holonic approach. Essential in this approach are 'holons'. A holon is an entity that is both a complete autonomous whole and a dependent, component part of a larger whole [21]. IOR supports the idea that only a system as a whole (the integral aspect) is responsible for its performance and a focus on parts does not help to fully understand the whole system's behaviour. Furthermore systems have to change from inside, by changing the organizational mind (orgmind) [22].

A system needs holonic capacity to be able to react from inside on turbulence in the system itself. Learning is the mechanism to acquire holonic capacity. De Sitter [16] refers to this as 'Self Design by Knowledge Transfer', which aims at developing and changing the orgmind [22], by very intensive education and training of the whole personnel. This mobilisation of human potential within the sociotechnical (self-managing team) structures spontaneously creates all kinds of new characteristics which make the system as a whole self-organizing, socially referring and self-replicating.

In addition IOR offers a specific view regarding the role of designers or change agents in the design process. The observer and the observed cannot be regarded as separate. Since the change agent and the system are mutually co-defined aspects of the same reality each playing an active role in co-creating the whole of which they are part [22]. This means that the employees that participate in the design process are also part of the whole that they design. It is therefore important that all employees that are in one way or another influenced by the redesign have the possibility to participate in the design process. This is what the participative aspect of PSIM stands for and this is something that is taken into account in the design process supported by the STSD tool.

8.4 Discussion

Both, the IOR and the KOMPASS approach have been integrated in the STSD tool (see Chapter 10) in order to make the tool comprehensive. This integration is based on the peculiarities as well as on the similarities of the two approaches. What they have in common are primarily the sociotechnical core assumptions that it is always an interaction of humans and technology that performs in work systems, and that the design of this interaction must be a participatory process. Both approaches comprise normative assumptions – although supporting an open and participatory process of system design and taking technology not as a design necessitarianism. These normative assumptions consist mainly in the perception of humans as beings that are capable of self-determination and of development. Thus, design solutions derived with the two approaches are autonomy oriented, i.e. tasks are designed in a way providing individuals, work teams as well as organizational units as much as possible with opportunities for self-regulated acting. Thereby in both approaches, in IOR as well as in KOMPASS, humans and technology are not perceived as two entities that can be conceptually separated and considered independent of each other. Humans and technology are rather considered as an integral whole. However, this integrality is conceptualized differently in the two approaches. Following these differences and their consequences for the STSD tool are discussed.

The main focus of KOMPASS is the task, which is considered to be the point of articulation between the human and the technology. Hence, it is the task that is performed in interaction of human and technology, be it on the level of human-machine function allocation, on the level of an individual's job or on the level of the interplay of the social and the technical sub-systems within a whole organization. On all three levels the human's part of the task is determined by organizational and technical design as well as by the human's capabilities and competencies. That means that the human part of a task is not determined by the technology or by the organization alone. One and the same technology for example, in dependency of its concrete implementation into an organization, can provide very different task requirements for the human. KOMPASS aims at a deliberate design of these task requirements. For that purpose it provides normatively deduced criteria for task design, from which requirements for organizational and technical design as well as for human qualification can be derived. As the KOMPASS criteria focus on the task, they consider executive, control and informational task aspects in an integral manner, i.e. a task design is aimed at in which these three aspects are balanced. The disadvantage of such an approach is that it provides support in balancing these three aspects within the task, but does not provide enough support for the integral design at the interfaces between the tasks.

Providing support for such an integral design is a strength of IOR. In this approach it is conceptually not differentiated between technical and social sub-systems that have to be considered in their interaction, but between sociotechnical sub-systems that are interrelated. IOR provides support for designing both, the socio-technical sub-systems as well as their interrelation. Differentiating between three aspect systems referring on production, control and information structure makes this possible. First the sociotechnical sub-systems are separated with reference to the production structure. The aim is to make the sub-systems operationally independent. Then the control structure and the information structure are designed in a way, providing each sub-system with complete control loops and hence with opportunities for as much self-regulation as possible. As these control loops are interleaved on different levels they also support the integration of several sub-systems. Thereby each sub-system can be perceived as a holon, i.e. as a whole of itself as well as a part of a larger whole. If provided with adequate conditions, the holons are not only self-regulating, but also self-developing.

As both approaches are based on the same assumptions and support participatory design, the results of their applications are very similar. However, by comparison, KOMPASS on the one hand has its strengths in its theoretically substantiated and well operationalized criteria, that are very useful in analyzing tasks on different design levels, and in determining good task design. IOR on the other hand provides an integral view regarding the different aspect systems, which is very helpful for developing design solutions. For the development of the STSD-tool (see Chapter 10) it has been taken advantage of these differences by making use of KOMPASS for the analysis part of the tool and by introducing IOR in the design part.

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9. Background of the Ergotool

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Abstract. To support the participatory and integral approach to improve ergonomics and efficiency of production lines, a software tool was developed within the PSIM project. It helps in the description and evaluation of current and future assembly processes. The E/S tool (Ergonomics/ Sociotechnics) tool has five modules, four of which deals with ergonomics: physical load, environmental hazards, mental load, and process flow characteristics. Together those four are called also as Ergotool. The focus of this chapter is on the background information and the development of the Ergotool. The procedural aspects of the tool are outlined in Chapter 10 (E/S tool). The tests of the Ergotool are described in Chapters 11 (Volvo), 12 (Finland Post), 13 (Fiat), 14 (Ford), and Chapter 15 (Yamatake).

9.1 Introduction

Assembly enterprises are under a lot of pressure. The market is forcing businesses to produce increasingly more varieties of products, and new product models are coming to production in shorter intervals. The customers become more demanding in terms of delivery time, reliability, quality and price. No surprise, then, that assembly process management is playing an increasingly vital role. Management of this aspect involves technical and organizational innovations to shorten order through-put time and lower the costs incurred by mistakes. Another crucial element is the availability of ergonomically healthy workstations that promote a motivated, efficient and healthy manner of working for employees. In the assembly industry there is an increasing awareness of the role of human factors for the success of the company, e.g. in a survey among 120 managers in the Dutch industry [7].

A current trend in development work is also the participative approach. Workers are participating in the design of their own work and workplaces. The reasons for that are various: workers' knowledge is useful, successful changes in workplaces can be made faster, and participation increases also motivation and commitment. Participation of company representatives is crucial, for reasons that have been discussed in previous papers on participatory ergonomics [4].

Another essential feature of the approach is the fact that two disciplines are brought together: assembly engineering and industrial ergonomics (Figure 9.1).

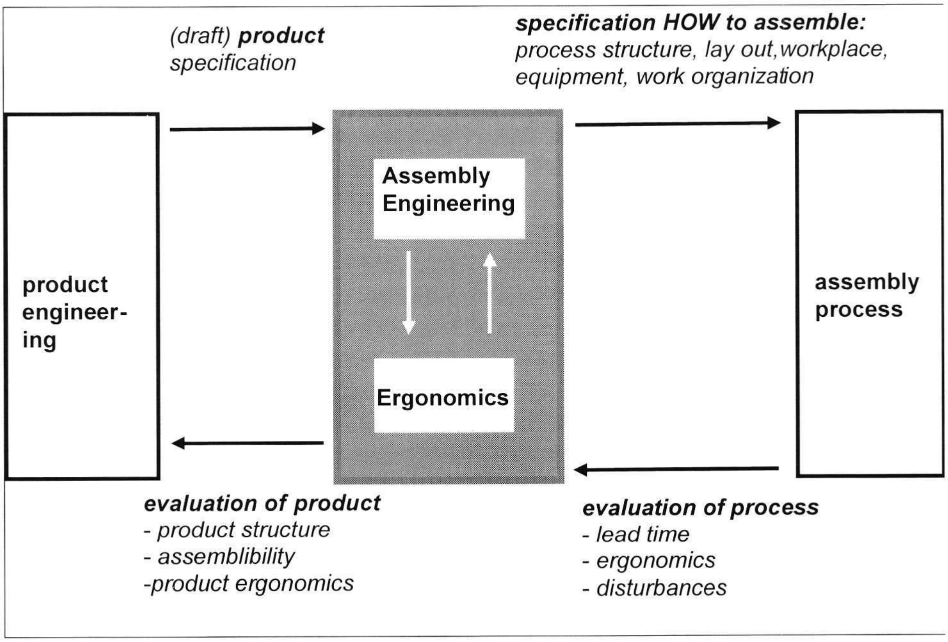

Figure 9.1 The Integration of Assembly Engineering and Ergonomics: An Essential Link Between Product and Assembly Process Development [3]

Previous projects demonstrated the added value of combining assembly engineering expertise with ergonomics expertise [1] [5].

To support this participatory and integral approach to improve production lines, a software tool, the E/S tool (Ergonomics-Sociotechnics tool), is developed within the PSIM project. The E/S tool is described in Chapter 10. This paper describes the four ergonomic modules of the E/S tool, which are here called also as the Ergotool.

Ergotool is a (software) tool that focuses on ergonomics and flow aspects in assembly processes. It should be of help in the participatory process of description, visualization and evaluation of current and future assembly processes and work-stations. It consists of four independent modules:

1. Process flow characteristics,
2. Safety and environmental conditions,
3. Physical load,
4. Mental load.

After developing and testing a paper and pencil version of the Ergotool, a software version was programmed and it was tested at Volvo, Finland Post, Fiat, Ford, and Yamatake Control Products.

The aim of this chapter is to provide background information on the four modules of the Ergotool: what ergonomic requirements and recommendations are used, and how they are transformed to guidelines in the Ergotool to evaluate risks of physical load, safety and environmental factors, efficiency of process flow, and the state of mental load. Some examples of guidelines are described and shown in detail. The procedure of the Ergotool is outlined in chapter 10 (E/S tool). Tests of Ergotool are described in Chapters 11 (Volvo), 12 (Finland Post), 13 (Fiat), 14 (Ford), and 15 (Yamatake).

9.2 Ergo Modules

9.2.1 Process Flow

The process flow module contains a checklist for efficient material flow in assembly processes. The main goals in material flow are optimizing space needs and minimizing manual material handling time. Mostly, they are in accordance with ergonomics criteria, but when disagreements occur, notes are given.

The following subjects can be evaluated:

1. Arrangement of workplaces,
2. Transportation of material between subsequent workplaces,
3. Lead time,
4. Separation of work area, part locations and transportation area,
5. Balance of activities along subsequent workplaces in (assembly)flow,
6. Test or inspection (of subassemblies),
7. Intermediate test or inspection of product (during final assembly),
8. Distance between supply location of parts and (assembly) work location,
9. Amount of parts on supply location,
10. Orientation/accessibility of parts on supply location,
11. Orientation/accessibility of parts on (assembly) work location,
12. Use of (assembly) equipment (for handling, mounting, orientation, fixation),
13. Information and guidance to support task (assembly and inspection).

A short explanation, possible benefits and evaluation guidelines are given in each subject. Most guidelines are qualitative, some guidelines are quantitative with exact numerical limits. The guidelines are given in the 'traffic light' form: green: no action needed; yellow: direct interventions preferred; red: direct interventions necessary.

Here two examples are shown in detail: arrangement of workplaces (Table 9.1) and transportation of material (Table 9.2).

Table 9.1 An Example of Flow Aspect - Arrangement of Workplaces - in the Paper/ Pencil Version of the Ergotool

Validation	**Green**	**Yellow**	**Red**
Separation of 'different' product families (substantially different in assembly sequence and components)	*Different product families are completely separated*	*Different product families are almost completely separated, sharing only expensive special equipment with high capacity (like paint spraying)*	*Different product families are not separated*
Material flow along subsequent workplaces	*Flow in one direction;* *no bypassing or back-tracking of work stations*	*Flow almost always in one direction;* *some bypassing of work stations (depending on product specifications)*	*Flow in different directions or flow direction is opposite to logic flow direction or crossings of flow occur;* *bypassing and backtracking occur (depending on product specifications)*

Arrangement of Workplaces

Explanation:

Subsequent workplaces should be arranged as much as possible according the logic direction of material flow (according the adding value chain).

Benefits:

- Easier flow of products: shorter lead time,
- Higher productivity: probably less manual transportation,
- Efficient use of space,
- Better overview of assembly process, easier to monitor and control,

Table 9.2 An Example of Flow Aspects - Transportation of Material - in the Paper/ Pencil Version of the Ergotool

Validation	**Green**	**Yellow**	**Red**
Distance	*None*	*Between 0 and 5 m.*	*More than 5 m.*
Frequency of manual transportation	*Once per 60 min.*	*Once per 15-60 min.*	*More than once per 15 min*
Towards intermediate location (buffer) or storage	*Never**	*Occasionally*	*Structural*

* *1. However, one of the ergonomic principles is to avoid paced work. In assembly work this may mean that a buffer area between subsequent workplaces is needed. In that case products shall be moved automatically or without any large physical effort from the buffer area to the workplace when the previous product is finished and sent away.*

2. In continuously moving assembly lines working areas must be long enough to make it possible to carry out work tasks without time pressure. Therefore subsequent workplaces must be separate enough.

Transportation of Material Between Subsequent Workplaces

Explanation:

The distance and frequency of transportation of material between the output location of a previous workplace to the input location of the next workplace should be minimized.

Benefits:

- Less handling distance and time,
- Less physical load,
- Less space,
- More overview and therefore possible to react e.g. on disturbances.

9.2.2 Safety and Environmental Factors

Introduction

The module Safety and environmental factors contains a checklist based on European standards on risk assessment concerning machinery [11] [12] [13] and Finnish risk analysis guidelines [14]. References include general health hazard lists, so the applications and guidelines were modified for assembly work only.

Two exceptions from the normal risk assessment process were done in the module. Normally all the work phases must be analysed from installation through normal operation and maintenance to dismantling of the workstation. Now only the actual (current or future) use (setting, operation, cleaning, fault finding, maintenance) of workstation is considered. The other exception was only to mention the two separate dimensions, severity and probability of possible accident, but not to include them in the checklist.

In the checklist guidelines on how to prevent the hazard are given as examples of good solutions. Based on experiences in Finnish industry it some space in the checklist was reserved also for comments of the participative group (see Table 9.3). For analyzing safety aspects the traffic light system is used in the following way:

Green: Insignificant, hazard is evaluated so small that no addition attempts are needed or hazard is in control in the current situation,

Yellow: Moderate, hazard is possible, but immediate corrections or stop of work are not needed. However, improvements should be made in a certain time limit. Also guidance and training may be necessary. Evaluation is yellow also then, when more specific analysis is needed,

Red: Intolerable, hazard is evident, probability of occurrence is high and consequences of occurrence are severe, improvements must be made immediately.

Table 9.3 Evaluation Form for Health Hazards. Evaluation is Done Qualitatively According to the Guidelines. If the Item is Not at All Possible (Hazard Does Not Exist), it Can Be Skipped and Marked "No".

Hazard				
Is the hazard potential?		no		
Examples for prevention	*Evaluation:*	G	Y	R
guidelines *examples of solution*	*Comments for identification of the hazard and improvements needed:*			

Safety and environmental hazards are grouped in four main groups:

1 Human transportation and passage:
   1.1 Slipping,
   1.2 Stumbling,
   1.3 Falling,
   1.4 Collision.

2 Machinery, tools and process:
   2.1 Cutting, shearing and punching,
   2.2 Crushing,
   2.3 Drawing-in,
   2.4 Ejection of parts or burs of process fluids,
   2.5 Falling objects from above,
   2.6 Machines, structures and materials falling down,
   2.7 Electrical hazard.

3 Operation of machinery:
   3.1 Control devices and display,
   3.2 Starting of machinery,
   3.3 Emergency stop devices.

4 Environmental factors:
   4.1 Lighting,
   4.2 Temperature conditions,
   4.3 Nois,
   4.4 Vibration,
   4.5 Radiation,
   4.6 Hazardous chemicals and materials.

As an example Table 9.4 shows one of the hazards in details: collision.

Table 9.4 An Example of the Environmental Factors Module - Collision –in the Paper/Pencil Version of the Ergotool

1.4 collision				
Are there any collision possibilities between workers and vehicles?		**no**		
Examples for prevention:	*Evaluation:*	**G**	**Y**	**R**
• *Transportation of materials and pathways of workers are separated* • *Doors do not open directly to transportation routes* • *Transportation routes are marked* • *Width of transportation routes according to loads and vehicles (plus 0.3 m. safety distance on both sides)* • *No shadow areas in pathway corners, mirrors used when necessary* • *No seeing difficulties when entering from light areas to dark areas*	*Comments*			

9.2.3 Physical Workload

Aspects of the physical load module are presented below, including the sources the guidelines are based on:

Physical Load Aspect	*Source*
1. Lifting:	NIOSH lifting equation [9],
2. Carrying:	Acceptable loads for carrying [2],
3. Pushing and Pulling:	Acceptable loads for pushing and pulling [2],
4. Static Postures:	Arbouw-richtlijn I en II [15],
5. Repetitive Movements:	Arbouw-richtlijn I en II [15],
6. Hand Forces:	Arbouw-richtlijn II [16].

The guidelines in the physical load module can mainly be given in a quantitative way. It is possible to state what are the numerical limits between acceptable and not acceptable situations. However, every physical load situation has many dimensions like duration, posture, frequency etc., so that some simplification and approximation must be done. Large differences between individuals cause that the same physical loading situation is always easy for some workers and too difficult to others.

Clearly within this module the two health limits can be discerned: between the green/yellow and the yellow/red areas. So it is possible to make a system, which according to the input data assess the situation in 'traffic light'-format:

Green: No increased health, risk action required unless health complaints in the population under consideration considered reveal,

Yellow: Increased health risk; make corrective action plan with preventive measures; direct interventions are preferred,

Red: Highly increased health risk; direct interventions necessary.

As an example guidelines for pushing and pulling are described in details.

Pushing and Pulling

Definition:

Pushing and pulling is defined as the 'whole-body' physical activity that concerns the horizontal transport of a weight supported on wheels, a floor or another surface. Both hands are held between waist and elbow height in front of the body (arms kept about straight); the load is horizontally moved with human force while walking at normal speed.

Input parameters:

P = horizontal pushing (Ph) and pulling (Pl) forces,
D = horizontal load transporting distance,
F = frequency of pulling/pushing actions during 8 hr shifts.

Guidelines:

The health limits in this item of the Physical load module are formulated in terms of the *initial* forces used to start the movement of a load and the *sustained* forces to keep the load moving (see Table 9.5). Longer lasting sustained forces are somewhat lower that momentary initial forces.

For push or pull forces of 25 - 30 kgf (250 - 300 N) the floor to shoe friction coefficients should be high enough. Therefore for slippery circumstances like wet, oily, or sandy floors, lower force values should be applied; consult an expert.

Table 9.5 Green/yellow and yellow/red limits in kgf (10 N) for sustained pushing (Ph) and pulling (Pl) for different frequencies F and transport distances D. Limits for female workers are in the italic. Data is valid for symmetric horizontal pushing or pulling at normal walking speed, two hands held between waist-breast height in front (arms about straight). If within cells Ph and Pl are not indicated, the limits are the same for pushing and pulling. n.a. means that the data on the area is not applicable.

<table>
<tr><td rowspan="2">F (#/ min)</td><td colspan="2">D≤2 m</td><td colspan="2">D = 2-8 m</td><td colspan="2">D = 8-15 m</td><td colspan="2">D = 15-50 m</td></tr>
<tr><td>green/ yellow</td><td>yellow /red</td><td>green/ yellow</td><td>yellow/ red</td><td>green/ yellow</td><td>yellow/ red</td><td>green/ yellow</td><td>yellow /red</td></tr>
<tr><td>≤0,5</td><td>17 10</td><td rowspan="2">Ph: 30 25
Pl: 20 17</td><td>14 17</td><td>Ph: 30 17
Pl: 20 17</td><td>12 5</td><td>Ph: 26 17
Pl: 20 15</td><td>7 5</td><td>14 8</td></tr>
<tr><td>0,6 - 2</td><td>15 8</td><td>11 7</td><td>Ph: 24 15
Pl: 20 14</td><td>6 4</td><td>14 9</td><td colspan="2">n.a.</td></tr>
<tr><td>3 - 5</td><td>13 7</td><td>21 15</td><td colspan="6" rowspan="2">n.a.</td></tr>
<tr><td>6 - 10</td><td>10 5</td><td>15 10</td></tr>
</table>

9.2.4 Mental Workload

Mental workload is the result of reaction to demand; it is the proportion of the capacity that is allocated for task performance [8]. The evaluation of mental workload in the Mental workload module is based on the three dimensional model which has been proposed by Neerincx et al.[3]. The dimensions of the model are:

- percentage knowledge based work,
- percentage time occupied,
- number of task set switches.

It should be noted, that many related organizational and psychological aspects are treated in the STSD module (see Chapter 8).

The dimensions can be depicted in a cube as in Figure 9.2. Mental workload not only depends on the work process and the workplace but also on aspects of the workers like training and experience. For this reason no absolute standards for mental workload can be given. Part of the procedure is the setting of standards for the situation in which the mental load module is applied. This is done in the current situation by establishing a value for each of the three dimensions for different scenarios (for different working situations like in normal routine work or during disturbances) and also measuring task performance and subjective mental workload. The latter two measurements are then used to establish the range of acceptable values on the three dimensions of the cube.

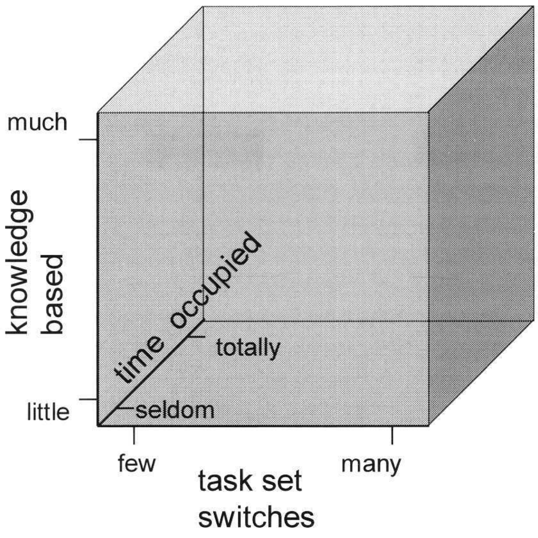

Figure 9.2 The Three-Dimensional Model for the Mental Load Assessment

How task performance is measured, has to be determined for each situation. Subjective mental workload is measured using the Rating Scale Mental Effort (RSME [10]). Where in the current situation a dimension falls outside the acceptable range, this dimension shows where solutions for the problem can be found. For example a high mental workload which is caused by a high score on the dimension '% time occupied' can be improved by measures to reduce the time occupied, e.g. reducing the amount of repair work within the assembly cycle.

The acceptability ranges which are established with scenarios in the current situation, can also be used to evaluate a new design for the process. In this case scenarios have to be simulated. A simulation which is as realistic as possible using the existing assembly line with real tools, with some form of pacing, yields the best results. In more abstract settings it is very hard to simulate mental workload because performing actions in a setting like that produces mental workload on its own account.

There are two optional methods in the mental workload module of the Ergotool: a Questionnaire method and a Simulation/scenario method. The Questionnaire method is intended for a first global assessment of the mental workload for all the tasks in the selected work area. The Simulation/scenario method can be used for detailed analyses of tasks which appear to have a mental workload too high or too low.

9.3 Conclusions

The four ergonomic modules of E/S tool seem to cover physical and mental characteristics of assembly work. According to the tests (the Chapters 11 to 15) reasonable and realistic development objects were found, and also some of them could be implemented.

Well defined formulas for evaluations were found only in one module: Physical workload. That part could directly utilise data from company's database and make assessment of work related health risks. The others need human interpretation. It can be, and preferably is based on a participative group, but also an individual can utilise the tool.

The tool must easily and effectively be used by working groups, designers as well as experts (ergonomists). The tests pointed out that the Ergotool should have at least two levels of complexity: "quick scan" level for less experienced to get the first impression of the main risks and a second level for experts to solve complex problems. The both levels will be necessary to guarantee participation of different user groups. A complex software structure will result in less involvement of especially inexperienced users.

The Ergotool can be used to analyse (a part of) a current assembly process or a (part of) a future assembly process, in which new products or new process steps might be involved. Ergotool can be used by ergonomists, manufacturing engineers, process engineers, management and assembly workers. It should preferably be used by working groups in a participative way, but can be used by individuals as well.

On the basis of the test results the final Ergotool characteristics have been defined and a demo of the tool is programmed in the software.

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10. The E/S tool

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Abstract. PSIM aims at a continuous and integral improvement of assembly processes. The E/S tool was developed to ensure that up-to-date ergonomic and sociotechnical knowledge is considered in these improvement processes. Designed to be used by employees of assembly enterprises, the tool offers support by means of visualizations and by means of a flexible procedure that offers structured guidance in optimizing the assembly environment. In this chapter the structure, the participative application procedure and the developed software prototype of the E/S tool are presented.

10.1 Introduction

Within the PSIM project a concept and a software prototype have been developed to apply state of the art sociotechnical and ergonomic knowledge in manufacturing enterprises. This E/S tool (Ergonomics/Sociotechnics tool) supports a participative approach enabling employees to improve or redesign their daily work considering ergonomic and sociotechnical aspects.

The *ergonomic approach* aims both at lead time reduction and improvement of the human assembly tasks. *Participation* of company representatives is crucial in this approach, for reasons that have been discussed in previous papers on participative ergonomics [1]. Another feature of the approach is that two disciplines are brought together: assembly engineering and industrial ergonomics. Previous projects demon-strate the surplus value of combining assembly engineering expertise with ergonomics expertise [2] [3].

The *sociotechnical approach* (SocioTechnical System Design or STSD) considers social and technical factors, therefore making interactions between these factors apparent and allowing a joint optimization that aims at avoiding technical biases in system design. Such biases not only neglect the potential of the human factor but - in the extreme - even destroy human potentials. Instead a system design is aimed at that explicitly considers the differences in strengths and weaknesses of both human and technical factors. The *participative* approach allows employees from different levels of the hierarchy and with different professional backgrounds (operators, supervisors, managers and engineers) to analyze their work and develop design solutions together. Consequently, the experience and knowledge of the involved staff is integrated in the problem solving process.

The E/S tool bases on the sociotechnical and ergonomic theory described in Chapters 8 and 9 respectively. In this chapter the relevant aspects of the E/S tool are described. First, the integration of ergonomical and sociotechnical theory is presented, then the procedure and structure of the E/S tool are explained, followed by the description of the prototype of the E/S tool and the conclusions section.

10.2 The E/S Tool: The Integration of Ergonomics and Sociotechnics

The E/S tool integrates the ergonomic and the sociotechnical approaches. The advantage of this integration is that reorganizations can be addressed in a comprehensive way. The reorganization of a manufacturing unit focusing on sociotechnical issues for instance would normally neglect possible ergonomic consequences, but as sociotechnical and ergonomic aspects can be analyzed and designed within the framework of one tool, possible interactions between sociotechnical and ergonomic aspects can be elicited and taken into account.

The E/S tool aims at supporting employees in the description, visualization and evaluation of current and future assembly processes focusing on ergonomic and sociotechnical aspects. To be able to focus on the ergonomic and sociotechnical aspects in a detailed way specific modules were developed that all support participative usage.

The E/S tool consists of four modules that focus on *ergonomic* aspects (the physical load module, the process flow module, the mental load module, the safety module) and of one module that focuses on *sociotechnical* aspects. Furthermore, there is a *shared task analysis* module that can be used in combination with the ergonomic and the sociotechnical modules. The modules of the E/S tool are graphically outlined in Figure 10.1.

The ergonomic and the sociotechnical modules 'share' the *task analysis* module as all these modules require a detailed description and definition of the unit of analysis (that part of an enterprise that needs to be analyzed and possibly redesigned) as a starting point. The shared task analysis module allows to choose which aspects are considered relevant depending on which module will be used in the next step (e.g. the mental load module) and allows to detect possible relations between different sociotechnical and/or ergonomic aspects at an early stage.

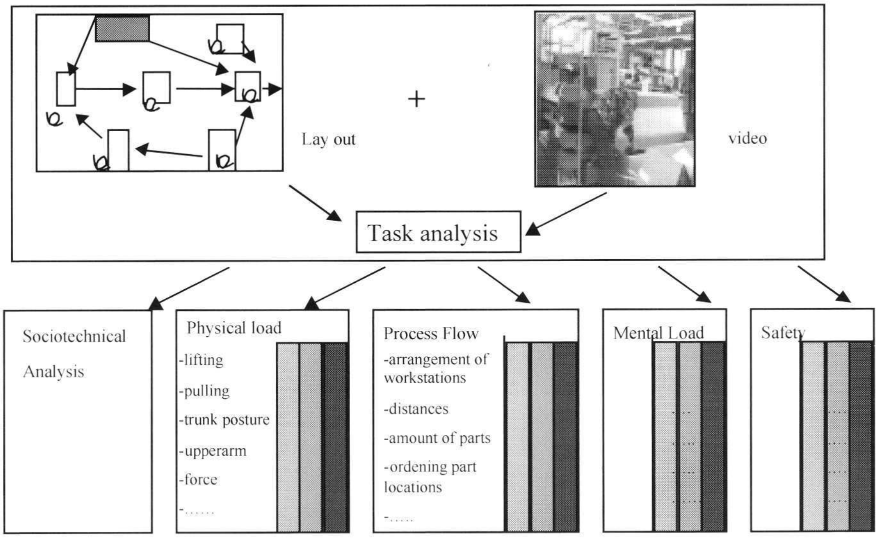

Figure 10.1 Outline of the E/S Tool Consisting of the Shared Task Analysis Modules, Four Ergonomic Modules and One Sociotechnical Module

The *physical workload module* evaluates the physical load in every assembly station according to guidelines (red/yellow/green). Green means "safe", yellow means "some risks, so measures must be taken" and red means "a lot of risks, so measures must be taken immediately". Tool users can evaluate aspects like lifting loads, pushing and pulling, static working posture, repetitive movements and hand forces. In this evaluation module we incorporated the most recently developed knowledge and standards on physical workload.

The *process flow module* evaluates process flows between different workstations and on every workstation according to guidelines (red/yellow/green). It considers aspects like arrangements of workstations, distances between workstations, amount of parts and order of part locations.

In the *mental workload module* users can evaluate the mental load based on a cubic model in which three dimensions play an important role: characteristics of activities (knowledge or routine based), time occupied and amount of task set switches.

With the *safety module* tool users can evaluate aspects concerning safety, and environmental factors using a checklist (red/yellow/green).

The *sociotechnical module* allows multidisciplinary project teams to analyze and design tasks of individuals and groups as well as work processes and work organization on basis of the sociotechnical approach. To support this process the module contains a flexible problem solving procedure consisting of different steps. For every step specific support is offered, e.g. visualizations, sociotechnical background information, criteria for analyzing and evaluating the work and the derived solutions as well as solution concepts and questions for adapting solutions to the needs of the unit of analysis. Starting points of the module use can be problems related to production processes and work organization, the evaluation of already existing ideas for redesign or the general goal to optimize production processes and work organization. During the STSD module use the project team is supported by a facilitator that coordinates the project team and can offer additional information.

The concept of the STSD module foresees that not all steps of this procedure need to be executed together in a group but that certain steps can be performed indivi-dually. This feature however has not been developed in the software prototype yet (see below).

It is essential to analyze work processes and work organization in detail, but the developed solution needs to consider the unit of analysis as a whole. Therefore the sociotechnical module supports a procedure that takes both an analytical and a holistic perspective into account by integrating the two sociotechnical approaches described in Chapter 8. The implementation of the two approaches is presented in the description of the sociotechnical module procedure in the next section.

10.3 The Procedure of the E/S tool

In the previous section the different modules of the E/S tool were presented. The shared task analysis module, the four ergonomic modules and the STSD module have different application procedures. With certain limitations (no connections to other tools or databases) it is possible to use the E/S tool as a stand alone tool. Integrated in the PSIM environment however, the PSIM procedure guides users to the E/S tool.

The PSIM procedure guides tool users to one or several tools depending on the issues that want to be addressed. Depending on the addressed issue(s) and the selected tool(s) the relevant organizational units of the enterprise that need to be considered for the analysis and redesign are defined (the unit of analysis) as well as the employees that need to participate in the optimization process. This group may comprise operators, manufacturing engineers, production managers, product de-signers, ergonomists etc. The steps of the PSIM procedure are scrutinized in more detail in Chapter 8.

As previously mentioned the E/S tool is designed for participative use. During the application of the tool it is required however that the user group is supported by a facilitator that can offer additional background information on the ergonomic and the sociotechnical approach respectively and that has experience in guiding project teams. The different steps of the E/S tool procedure are described below.

10.3.1 The Collection of Sociotechnical and Ergonomic Inputs for the Task Analysis Module

In this step the tool users perform several activities. Depending on which of the modules will be applied in the next step (modules for ergonomic or sociotechnical analysis and design) the focus on the different aspects of the task varies.

A graphical representation of the assembly lay out in the user group is made. This lay out focuses on three levels: (1) general lay out, (2) workstations and transport-ation lines and (3) the tasks performed on the workstations.

A video-recording of each assembly process step can be made. Ergonomic data can be elicited, if required for detailed evaluation. On basis of this input the user group makes an ergonomic assessment of the current situation. Then the user group enters the results of the assessments into the E/S tool and they will be stored into the E/S tool database.

To analyze organizational aspects the tool users have to answer several questions regarding the current situation of the organization. The tool presents visualized schemes of the unit of analysis in which the user group is asked to mark communication and process paths. Employee related questions focus on the number of staff, the level of education, the tasks the employees have to perform, the number of employees directly involved in the production process and the number of employees not directly involved in the production process. Questions related to the organization focus on the overall organization (hierarchy levels, teams etc), communication paths, interfaces with other organizational units and the wage system, e.g. are individuals or teams rewarded. Questions related to the tasks focus on the task(s) of the unit of analysis, input and output relations referring to information and material flow as well as the tasks of the individuals. Finally the tool user(s) have to list problems they face in their work. The input gained by these questions is stored in the E/S database and will be used later in the design phase, which is part of the STSD module.

10.3.2 The Sociotechnical Module - See Chapter 8

The procedure of the sociotechnical module consists of two phases. The analysis phase, based on the KOMPASS method [7], and the design and evaluation phase, based on the Integral Organizational Renewal (IOR) approach [4] [5] [6].

Sociotechnical Analysis of the Current Situation

The aim of this phase is a detailed sociotechnical analysis of the current situation of the unit of analysis.

First the objectives that need to be achieved are defined. This step is supported by four categories provided by the STSD module to assure that relevant aspects of production units are not neglected: Business management, organization, employees and technology. The collected objectives are then clustered according to similarity, for each cluster a name is defined that expresses best the essence of the cluster and finally the objective clusters are prioritized. The clusters are then used for a first assessment of the unit of analysis.

After providing the project team with the essentials of the sociotechnical approach, the criteria for the sociotechnical analysis are introduced and applied for analyzing the current situation of the unit of analysis. As a final step the criteria are related to the objectives thereby developing a network that will enable the project group in the next phase to evaluate developed solutions systematically. The STSD module automatically summarizes the analysis made in this phase in a report.

Sociotechnical Design and Evaluation

In this phase the user group is provided with conceptual solutions as support for generating and designing concretized solutions for reaching the objectives. This step focuses on the holistic perspective by offering conceptual solutions in terms of organizational structures with certain characteristics. The module stimulates the tool users to learn from these alternatives and to apply what is useful for their situation.

To concretize the concepts to the needs of the own situation a list of questions is offered. Moreover the tool provides the tool users with the information they gathered in the task analysis module to support the development of an adequate design.

Then the tool users evaluate their solution by means of the network containing the criteria and the objectives developed in the previous phase. For every criterion the project team has to assess the expected change of the solution, the network then visualizes the effects on the objectives. Based on this evaluation it is decided whether the solution needs further improvement. The result of this phase is a concretized and systematically evaluated solution for redesigning the unit of analysis.

10.3.3 The Four Ergonomic Modules - See Chapter 9

The ergonomic modules can be used on two levels. Firstly, for the ergonomic evaluation of the unit of analysis all the checkpoints of the modules are considered one after another, thereby the project team discusses all ergonomic aspects participatively. Secondly, if during redesign solutions are found, that might increase the load for workers only on a certain ergonomic aspect, the respective items in the modules can be checked. This focused approach, however, requires skillful tool users that have a good ergonomic background.

The input from the task analysis module is necessary especially for the physical and mental load modules. They rely on detailed information of task characteristics like forces, body postures and time periods. Without this data the use of the ergonomic modules gives unreliable results.

The procedure to use the ergonomic modules is the following:

- Evaluation of the current ergonomic situation using the four ergonomic modules. The tool automatically summarizes these evaluations in a report,
- Generation of possible alternatives (improvements). This is done by the participative project team and is supported by the modules when comparing alternative designs with each other,
- Evaluation of the selected alternative to be implemented.

10.4 The Software Prototype of the E/S Tool

After developing and testing a paper and pencil version of the E/S tool, a software prototype was programmed. The prototype allows to work participatively on ergonomic and sociotechnical aspects as described above and can be used as a stand alone tool. The prototype consists of the task analysis module (for both the sociotechnical and the ergonomic modules), the sociotechnical module and four integrated ergonomic modules. Following the task analysis module and the sociotechnical module prototypes will be described.

10.4.1 The Task Analysis Module

If the PSIM procedure guides the user group to the E/S tool (see above) the task analysis module is presented. A possible starting point of the task analysis module is a lay out of the assembly containing workstations and lines of transportation (see Figure 10.2). By clicking on a workstation or a transportation line descriptions of the tasks performed at that workstation or transportation line can be entered and recalled at any later point. It is then required to fill in data of the current situation in the tool as previously described. As a next step the user group can choose to work with the sociotechnical module or the ergonomic modules.

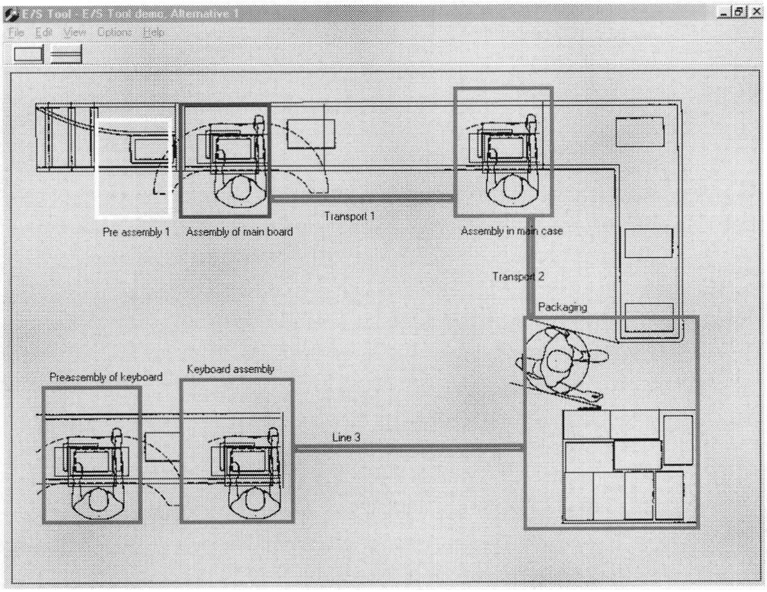

Figure 10.2 Visualization of the Lay Out Containing Workstations and Transportation Lines as Presented by theTask Analysis Module

10.4.2 The Sociotechnical Module

Within the sociotechnical module prototype the procedure consisting of the two phases and the features (e.g. visualizations, criteria-objectives network, theoretical background information) were implemented. As a starting point the prototype presents and overview of the procedure that can be viewed at any later point again. It is not required to perform the steps in the listed sequence, steps can be repeated or previous steps can be reconsidered. For every step described, the prototype offers specific support and the result of each step is stored in a database:

Sociotechnical analysis of the current situation:

- Step 1: Defining concrete objectives,
- Step 2: Describing the relevant system with the objectives,

- Step 3: Explanation of the theoretical background,
- Step 4: Explanation and application of the tool criteria,
- Step 5: Relating the objectives to the criteria.

Sociotechnical design and evaluation:

- Step 6: Generating solutions,
- Step 7: Concretizing solutions,
- Step 8: Evaluating solutions.

Based on the requirements of the industry partners of the PSIM consortium, a selection of the criteria of the KOMPASS method (Chapter 8) was made and integrated in the prototype for step 4. The selection included the following criteria:

Criteria on the level of the work system:

- Independence of the work system,
- Task completeness of the work systems,
- Autonomy of the work system,
- Polyvalence of the work system.

Criteria on the level of the individual task:

- Completeness of the individual task,
- Task variety,
- Amount of decision making and planning,
- Flexibility.

Also based upon the requirements of the industrial partners the conceptual design solution offered in step 7 of the procedure was limited in the prototype to Self-Managed Work Teams.

Chapters 11 and 12 contain descriptions and evaluations of the application of the prototype of the sociotechnical module.

10.4.3 The Ergonomic Modules

The outline of the software prototype of ergonomic modules is shown in Figures 10.3 and 10.4. Most required input is numerical data or selecting one of the options given by the software. Options can be very distinct and need measurements in workplaces (or direct data from company's database). Some evaluation items are, however, qualitative, and the result of analysis bases on the input of the participative group.

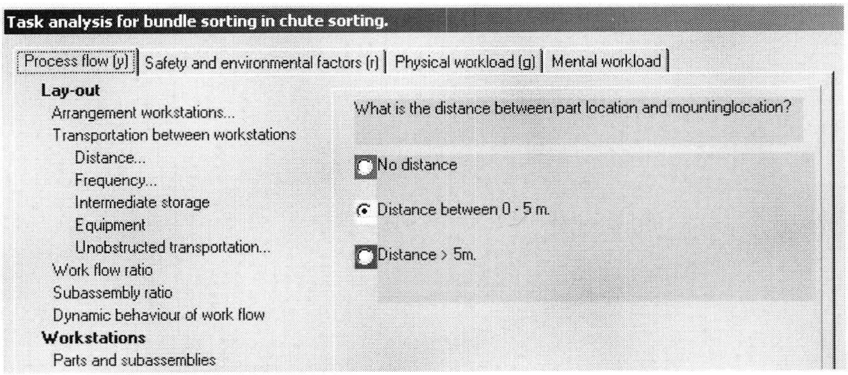

Figure 10.3 Evaluation of Transportation Characteristic in the Process Flow Module

To help the evaluation video clips can be linked to the tool. This helps in the analysis of ergonomic features, but it has also a drawback, because it might concentrate the discussions to the points outstanding in the video.

The results of analysis can be seen in the layout picture in the traffic light format (Figure 10.2). Squares which mark the workstations change their color according to the evaluation: if one aspect of a workstation in the ergonomic modules in red, the square will be red, too.

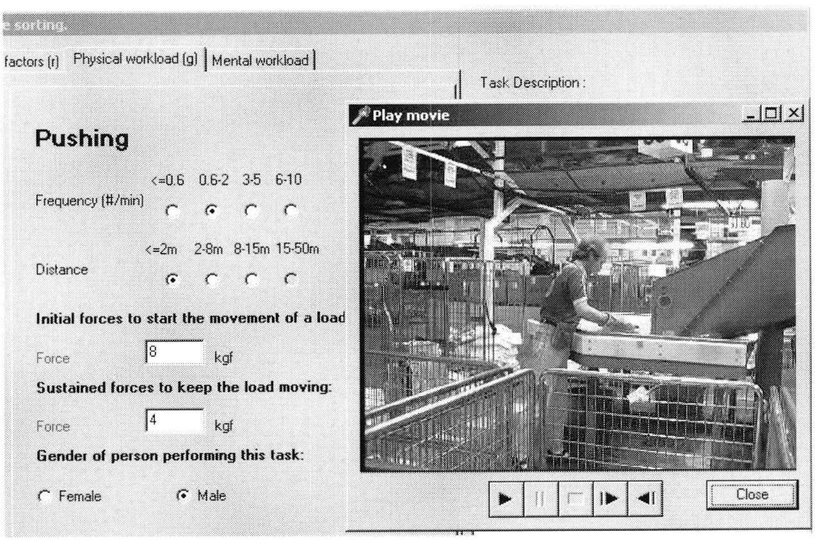

Figure 10.4 Evaluation of Required Pushing Forces in the Physical Workload Module. Video Clips Showing Actual Work Tasks Can Be Very Helpful in Participative Group Discussions.

10.5 Conclusions

The E/S tool is unique regarding the integrated approach of sociotechnical and ergonomic knowledge that employees can apply in a participative way supported by a software environment. Besides this the participative use of the tool is essential enabling groups of employees from different hierarchical levels and functions to work on improvement of the current work situation.

The software prototype test was considered as successful by both tool users and tool developers (see Chapter 8 and 9). The test of the tool demonstrated the value of involving work staff in companies and working in these groups on organizational and ergonomic problem solving, supported by an ICT tool. This enables the users to find solutions which are accepted by all stakeholders. Although designed to operate without intensive support of experts, a process facilitator proofs to be of considerable importance in the tool use. Nevertheless the E/S tool can be used by workgroups as well as experts (both sociotechnical and ergonomic).

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11. Test at Volvo

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Abstract. This chapter describes the tests of the prototypes of the sociotechnical and selected ergonomic modules of the E/S tool (see Chapter 10) at the Final Assembly shop of the Volvo Cars plant in Torslanda, Gothenburg, Sweden. One section of the production line was videotaped and evaluated according to the E/S tool and the PSIM procedure (see Chapter 7). To test and evaluate the selected modules of the E/S tool two workshops were carried out, one focusing on sociotechnical aspects the other focusing on ergonomic aspects. Both the ergonomic and the sociotechnical modules were well received among the participants. The workshops showed the importance of a participatory involvement of employees when considering ergonomic and sociotechnical aspects of the development process.

11.1 Introduction

Within the PSIM project, the concept and a software prototype of the E/S tool have been developed (see Chapter 10). The E/S tool (Ergonomic/Sociotechnical tool) offers support for ergonomic and sociotechnical analysis and design. The E/S tool consists of a task analysis module, four ergonomic modules (physical workload, process flow, mental workload and safety) and a sociotechnical module. The tool was conceived for participative use, involving multidisciplinary project teams in the analysis and design processes. This chapter describes the tests of the prototypes of the sociotechnical and selected ergonomic modules of the E/S tool at the Final Assembly shop of the Volvo Cars plant in Torslanda, Gothenburg, Sweden.

Two workshops were planned and carried out to test the different modules. In the workshop that focused on ergonomic aspects, the modules physical load and mental load were applied. The safety and process flow modules were demonstrated to the working group, but not actually applied. In the other workshop, the sociotechnical module was tested.

One objective of the tests was to generate ideas for improvements in efficiency and health of a selected part of an assembly line (the unit of analysis) at Volvo, considering physical load and sociotechnical design. The second aim was to evaluate the selected E/S tool modules, thereby eliciting the strengths and the aspects of the E/S tool that need improvement.

11.2 Volvo Cars Corporation

Volvo Cars is a car manufacturer that has gone through large changes during the last decade. The market demands new car models at an increasing speed. Being quite small in global market terms, an effective development process and flexible manufacturing systems that can handle several development processes at the same time as well as producing several products in the same production system are required. To meet these requirements, a flexible organization at the shop floor and an integrated product and process development are needed.

11.2.1 Test Site Description

The unit selected for analysis was a section towards the end of the final assembly, line 1:71. The station 'hanging doors on car' of that line was of main interest for the ergonomic modules.

The reason for this selection was that the same station was previously studied in the 'as is' study in PSIM (spring 2000). Since then it has undergone several changes due to production efficiency projects, which have increased the ergonomic problems. Furthermore, a larger organizational change is planned for the spring of 2002 and preparations for this are ongoing. This coming change was focused on in the tests.

The assembly line of the test site has a length of about 105 meters. The cars move on a conveyer belt at a constant speed that can not be influenced by the operators. The speed of the assembly line was app. 58 cars per hour. There is a day shift (from 6:30 a.m. to 3:24 p.m.) and a night shift (from 3:30 p.m. to 0:24 a.m.).

The test site has about 40 to 45 operators. There are eight different tasks (attaching the doors, attaching the roof rails etc., see table 5.2 for details) being performed on the cars. All operators know all tasks. Every 30 minutes there is a rotation and the operators start working on a different workstation. The operators can call on a resource manager whenever they have a problem or comments to state, e.g. about quality problems of a part that has to be assembled.

The tasks the operators perform on the assembly line are purely manual and highly repetitive. Also, there is hardly any flexibility within the tasks, i.e. when to do the tasks and how to do them.

All operators are included in a KLE team. The KLE team is responsible for quality, delivery, precision and economy and needs to deal with human resources and technology to manage its responsibility. This means that a number of normal support functions are included in the production teams' tasks. To facilitate the teams, there is a support organization, including ergonomics, production engineering, quality, measurements etc.

11.2.2 Ergonomic Work at the Shop Floor

At the final assembly shop, there is one ergonomist, and one full-time employee responsible for work technique. The ergonomic evaluations are done systematically station by station, and also upon requests from operators, production technicians etc. and on basis from rehabilitation statistics. It is also the ergonomists' responsibility to inform and educate on ergonomics for all categories of staff.

Volvo has its own ergonomics standards and requirement specifications, based on Swedish laws but also complemented with new research, former experiences and statistics. The ergonomics data from the factory is all stored in a central database. Once a problem is detected and classified, the problem is discussed and handed over to the production technicians. Even though the ergonomist has no formal responsibility for the solution of the problem from the owner, he/she normally takes an active part in suggesting solutions or work-arounds. For financing, smaller investments can be decided at the basic production engineering level, while larger investments must be cleared at the a higher level.

11.2.3 Development and Ergonomics

During a new car development project, at certain milestones, all aspects of the car are evaluated (including producability and process availability) in parallel. The results are summarized and directions for how to continue the project are derived.

All process related aspects are summarized in a scorecard. For each assembly task, a detailed instruction (PKI) is evaluated on a number of aspects, such as quality, sequence, assembly path, ergonomics and several other parameters. Each parameter in the scorecard is evaluated with respect to current project status. For those parameters not having a satisfactory level, a problem description, solution and deadline is decided. The Manufacturing Engineer (a.k.a. the '*beredare*') is the one responsible for the process related evaluation. To his help he has a variety of simulation tools. But since he does not have the knowledge to evaluate all aspects of the manufacturing system, he has to get help from other 'local experts'. He gathers them at meetings and together they evaluate the parameters and fill in the scorecard.

The development projects have an internal resource for supervising ergonomics when introducing new products or major product changes. Both the beredare and the ergonomist have responsibilities regarding the ergonomics rating on the score card. In general, the beredare sets the initial rating. If the setting is not trivial, he calls for help from the ergonomist. The beredare also has the possibility to use state-of-the-art ergonomy tools, such as computer manikin software. If that is the case, the specified PKI is simulated by a simulation engineer, and the engineer, the beredare and often also the ergonomist and production people e.g an operator or production technichian together reach a conclusion on the basis of the simulation.

Sociotechnical aspects are also considered in the development projects, but not in the same structures way as traditional ergonomics. This responsibility is also the ergonomists'.

11.3 Scenario and Procedure of the Tests

To be able to test in a realistic situation, a specific situation – a scenario – has to be chosen. As large changes were planned for line 1:71, these were addressed as the scenario. The changes are in short:

- A re-organization. The hanging of doors is connected to a new door-line building the whole door, the line will be its own department. Daily rotation between line 1:71 and the door line will take place,
- The new door-line gives a new fixture for transporting the doors with a new lifting tool as a consequence,
- More support functions should be performed by the operator teams as 'new' KLE-teams are implemented (implemented all over the Final Assembly shop).

This scenario of changes was treated according to the process described for process development (see section 11.2.3). The procedure followed normal Volvo evaluation, but takes small steps towards future plans. A wider range of ergonomics and socio-technique evaluations were added through an extended scorecard based on the parameters treated in the PSIM tools. The 'new' parameters were physical load, safety, process flow, mental load, individual work task and work system. The evaluations of the parameters were derived during the test workshops with help of the tools. These new parameters were mainly evaluated on a station or line level, an evaluation level that also was new compared to the instruction level normally used at Volvo.

11.4 The Ergonomic Modules Test

In order to make this test, several preparatory actions were taken by both Volvo and PSIM participants. A preliminary definition of the stations of the assembly line to be evaluated, and setting up a working group to be involved in the test had been carried out prior to the actual test. A procedure was defined and participants were selected.

11.4.1 Preparations

For each workstation in the selected line section, the following activities were performed by an ergonomic expert:

- A video was taken of operators performing their tasks/job. Movements, postures and all activities were all recorded several times,
- Distances (walking, reaching etc.) were measured,
- Operators were asked to do their job as they usually do.

Every workstation was analyzed with help of video, the measurements and the E/S tool. First, the tasks performed at every workstation were listed in the tool. In the next step, every task was analysed with respect to physical load. This was done in the tool using the video for analysing posture, task time, and frequencies. Data from the video and from other measurements were entered into the Ergotool. Risks concerning physical load were also analysed.

11.4.2 Procedure of Group Sessions

The procedure tested at Volvo was the participative part of the tool specific PSIM procedure. The aim of the procedure was to gather all parts with interest in the specific ergonomic issues to be analysed. The procedure used for the group session was in line with the general PSIM procedure.

For the ergonomic module workshop, a mix representing all interested parties was summoned. This included representatives from each of the following groups: Manufacturing Engineer (*'beredare'*), Production technician, Production leader, Operators (two), Verification and simulation expert, Ergonomist, Union safety ombudsman, and Union representative.

After an introduction to the PSIM project, and of the participants and their respective functions, the participants were initiated to the aim of the specific workshop. The different tasks for the line station (1:71) were listed and a problem list for the station was created. Even though a document with problems had already been created by an ergonomics expert, the participatory aspects were valued; hence the choice to recreate the list based on the participants views and comments. Also, not only the ergonomy problems were to be listed, but all problems related to the station. To support the creation of the problem list, a video tape showing the tasks for the station was presented to the participants.

The problems from the problem list were then graded and timed, using the ergonomy modules of the E/S tool. Then, coming changes as well as possible solutions to problems were discussed.

The session was concluded with the filling in of a questionnaire where both the participatory aspects and the Ergotool aspects of the session were to be graded.

11.5 Results from the Ergonomic Module Test

In the following section the results for line 1.71 from the group session and the test with the Ergonomic modules are presented, including examples on the list of tasks, time per worker per day, changes in workstations, problem areas and scores.

11.5.1 Task and Problem Analysis

The zones and activities at the 1:71 line, including the time per worker per day were identified by the working group, see column one and two in Table 11.1. The activities concerning the hood, trunk and suspension were not evaluated in the workshop and are therefore excluded from the list.

Recently implemented changes and daily problems areas were also identified (see column 4 and 5, Table 11.1). At every workstation the most recent Volvo scores were added. Volvo score: load level 1 (green) means: no harmful influence on the body, load level 2 (yellow) means: probably not harmful influence on the body, and load level 3 (red) means: harmful influence on the body. Note: These Volvo scores were identified before the named changes. In column 6, Table 11.1 the physical load scores for workstations 1 to 4 are shown as well.

Table 11.1 Summary of Results from the Ergonomic Modules Test at Line 1:71

Zone time/day	Activity	Volvo eval.	Changes	Problem area	Phys load
1. Tank ***0,5 h/day***	Putting on hoses Filling the tank Taking off hoses	2	Extra activities during filling time (trunk, hood, ..)	'Boring job'	G
2. Liquids ***0,5 h/day***	Putting on hoses Filling fluids Taking of hoses Closing the lids	2	From 2 to 1 person Idea: hoses closer by the car Idea: working technique: step instead of reach	Reaching and pulling Hurry between cars Lids hard to screw Sometimes slippery	Y
3. Roof rails ***0,5 h/day***	Putting on rails across the roof Fastening rails Putting on 3 plastic covers	2+	Station was moved Higher platform Plastic covers are improved From 3 to 2 people	Time pressure when 3 in a row >60° arm elevation for smaller people	Y/R
4. Doors ***4,5-5 h/day***	Attaching hooks Pullinglifting tool Attaching cables Hanging door to hinges Attaching screws Getting machines Tightening screws Putting away machines Measuring/Adjusting doors Putting cables in place Adjusting front door Placing pdf panel Putting off prot. cover	3-,3	From 7 to 6 persons Hinges are changed (higher quality, New fixture for hooks (less adjusting time, less pulling) From 4 to 8 spots to measure 'bonus' work has moved to the line 'button' for swinging door body people measuring door arch line operators doing the rest	Accepting the fixture (attitude, training) Fixture not always work (body/door variation) Fixture must fit in new models Pushing/shaking lifting tool for different angles Twisted/bended posture Pressure on thumbs Time pressure Not much room (new model better) Noise from conveyor	R
4.Front door ***0,5 h/day***	Pulling lifting tool Hanging door to hinges	3-, 3	1 person	Same as above marked in italics, 4. Doors	R

11.5.2 Evaluation on Physical Load, Safety, and Mental Load

The evaluations made in the three ergonomic modules of the E/S tool are presented below. Risks concerning *physical load* were identified in Table 11.2.

Table 11.2 Explanation of the Ergotool Evaluations and Risks Identified

Zone	Physical Load	Overall Score
1. Tank	No problems: green	Green
2. Liquids	Stretching and reaching: bending working posture Gripping and turning lid: arm and wrist load, bended posture, force	Yellow
3. Roof rails	Mounting on or above shoulder level: arm elevation Torque powertool: 6Nm (<2 kgcm in hand), wrist deviation	Yellow (0,5-1 hr a day) Red (whole day)
4. Doors	Trunk rotation, neck torsion and bending Standing on one leg	Red
5. Front door	Trunk rotation, neck torsion and bending Standing on one leg	

Regarding *safety* at the 1:71 line, some risks were identified in the group session, using the Ergotool. Risks were due to noise (sometimes >85 dB(A) at the door station) and temperature (sometimes < 20°C). Other risks were not applicable and the risk of falling was mentioned as very unlikely (green).

Volvo developed a new lifting tool, and a prototype in a lab was tested by the working group. All safety aspects of this new tool were already checked by Volvo. Noise level was supposed to be reduced to 70 dB(A) due to legislation (green).

Mental load in line 1:71 was discussed in the group using a checklist and the Ergotool. The outcome of this discussion is that the work done by a trained operator is experienced as 90% routine based and 10% knowledge based. The knowledge based part can easily increase, for instance when there is a quality problem of parts. If there is some quality problem (for instance roof rails) the operator has to ask for assistance (resource) several times a day. This will increase the mental load. According to the group, operators are mentally occupied for 75% (average) of the work time. For some workstations this is more (100%), for others it is less (50%). This part of the work time requires concentration. The amount of task set switches on every workstation is minimal. The amount of task set switches on every day is 7-8 because of rotating over work stations. The amount of task set switches (disturbances) will increase if there is a quality problem of parts, or during an introduction of a new (lifting) tool, or a new operator etc.

When for instance a new lifting will be introduced, % knowledge based, % time occupied and amount of disturbances (questions of colleagues) will raise during learning time (4-6 weeks). To gain normal speed and to do the job in a skill based way will take 10 weeks. The conclusion is that mental load will rise during learning time. Extra person(s) during that time period could be considered.

11.6 Evaluation of the Ergonomic Modules Workshop

All participants rated the tool as a useful tool not only to improve ergonomics, but also to use as an argument when discussing ergonomics with supervisors.

The participatory process where several individuals with different functions and objectives meet to discuss and develop solutions were considered normal procedure and presented no unfamiliar situation to the participants. Even so, it was considered highly valuable.

Due to technical problems and the status of the ergonomic modules prototype, not many comments about the user interface and the actual implementations were relevant. A few important changes to the tool were suggested, such as a new rating system on the total result of a station. Another important suggestion was feedback to the user: the tool should show why tasks become 'red'. The guidelines should be incorporated in the ergonomic modules. Input parameters as well as the outcome ('borders') must be well defined for the user. Other important issues raised include the qualifications of the user of a future E/S tool, how to define the size of a task and the supervisor´s role in the ergonomic module (merely to introduce the terminology and to instruct on how to build the task analysis. The grading of the tasks can be done without any supervision).

11.7 The STSD Module Test

The STSD module workshop to test the E/S tool at Volvo took place one week after the test of the ergonomic modules. The same Volvo employees participated, i.e. the following roles were represented: One manufacturing engineer ('*Beredare*'), one production technician, one production leader, two operators, one verification expert, one ergonomist, one union safety ombudsman and one union representative.

As mentioned above, the participative involvement of employees for improving the work environment is well adopted and part of the company culture. The participative approach of the STSD module therefore was not unfamiliar to the participants of the workshop. During the workshop that was facilitated by a STSD specialist of the PSIM consortium, the software prototype of the STSD module of the E/S tool as described in Chapter 10 was used.

11.7.1 Problem Definition

After a short introduction of the different participants of the workshop, the first step was to define problems of the unit of analysis that can be addressed with help of the STSD module. Each participant listed the problems that according to his/her opinion were relevant. Together the project team agreed on the following main problems: The implementation of the KLE teams is inadequate, there is insufficient communication between production and management (top down as well as bottom up), the variation in work is low and the integration of the different departments is insufficient. Based on these problems objectives were defined.

11.7.2 Analysis Phase

The STSD module procedure consists of two phases, the analysis phase based on the KOMPASS method [1] and the design and evaluation phase based on the IOR approach [2]. This procedure was applied to define objectives that need to be achieved, to analyze the current situation of the unit of analysis and to evaluate the upcoming changes of the unit of analysis.

Based on the defined problems, the first task of the project team was to define objectives that the unit of analysis should aim at. Every participant had to reflect according to his/her point of view, which objectives should be achieved. To structure the objectives and to assure that the relevant aspects of manufacturing units are considered, the STSD module offers four categories for defining objectives: business management, organization, employees and technology. Based on this analysis the following objectives were defined:

1. Transparent communication,
2. More variation of tasks,
3. Employees have a sense of unity,
4. Motivating tasks.

The objectives were prioritized as listed above. For every objective the project group then had to rate the current situation of the unit of analysis. The assessment of the objectives showed for which objectives the situation is considered worse than for others. The result of this step is important at a later point of the STSD module procedure, where the objectives are related to the module criteria. The objectives and the assessment of the objectives were entered into the STSD module by the workshop facilitator.

Next the basics of the socialtechnical approach were presented and the purpose of the STSD module criteria applied in the next step was explained. The criteria of the STSD module base on the KOMPASS method [1] and are described in Chapter 8. The criteria support the analysis and the design of manufacturing units on basis of the sociotechnical approach. Previous to the test a selection of criteria was chosen for the application at VOLVO. On the level of the work system the criteria independence and polyvalence of the employees were chosen, on the level of the individual task the criteria task variety, planning and decision making requirements as well as influence over working conditions were chosen. For every criterion the STSD module provides a short explanation and a scale for rating the current situation to support the project team in the sociotechnical analysis. For every criterion the project team had to agree on a score representing the current situation and a reasoning of the score therefore integrating the different points of view of the participants.

As a last step of the analysis phase the criteria were related to the objectives. For every criterion the relations to the different objectives had to be defined. The result of this step was a network connecting the criteria to the objectives. This network was central in the next phase for evaluating the upcoming changes in the unit of analysis.

11.7.3 Design and Evaluation Phase

The unit of analysis was about to undergo several major changes. One was that the unit was about to be merged with another related manufacturing unit, the other change was the introduction of a new KLE concept. The focus in the workshop was mainly on the latter point although some aspects could not be analyzed without considering the merger of the two units. As the KLE concept had already been elaborated by VOLVO this concept was analyzed and concretized (instead of the SMWT concept suggested in the prototype of the STSD module).

The new concept of the KLE teams was presented by a member of the project group. The concept had at this point not been concretized yet considering the situation of the unit of analysis. Therefore the project team discussed requirements for a successful implementation of the KLE concept and addressed first steps of concretion.

A basic requirement for a successful functioning of the concept stated was that the operators are provided with a specified amount of time each week for performing the KLE tasks. In addition to the daily official meeting unofficial meetings at lunch would increase the sense of unity of KLE teams. The distinction between the roles of the supervisor, the team leader and especially the resource manager still needed further clarification. The team leader will take over some responsibilities of the supervisor however. The role of the team leader was characterized as follows: The team leader is responsible for the six minutes morning meeting, (s)he knows the skills of the KLE team members and cooperates with other team leaders. Most of his/her daily work however still consists of assembling.

The supervisor's role changes in that (s)he is responsible for communication to higher levels of the organizational hierarchy and is more involved in joint coordinating with other supervisors, thereby focusing more on organizational aspects and long term planning.

The KLE team is responsible for solving problems autonomously and for electing the team leader. The different members specialize on one task but ideally can perform all the tasks within the assembly responsibility.

After analyzing the KLE concept the simulation network developed in the analysis phase was used to evaluate the expected effects of the introduction of the new KLE teams on the defined objectives. Figure 11.1 contains the visualization of the positive effects as presented by the STSD module in the workshop.

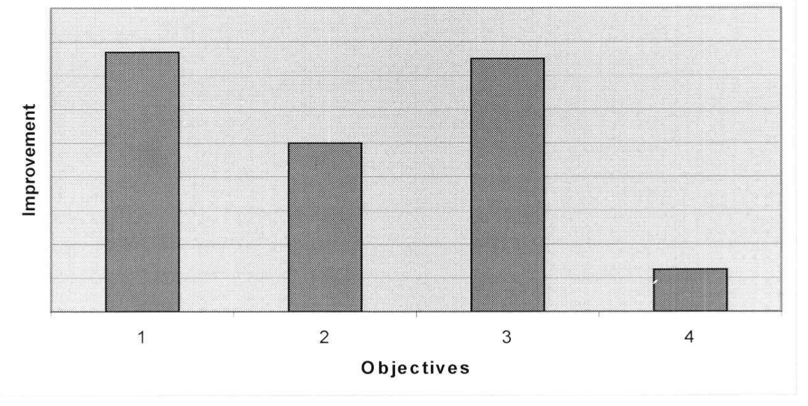

Figure 11.1 Visualization of the Expected Effects of the Introduction of the KLE Teams on the Defined Objectives: 1) More Variation of Tasks; 2) Sense of Unity of the Employees, 3) Motivating Tasks, 4) Transparent Communication

Figure 11.1 shows that the introduction of the new KLE teams is expected to improve the variation of task and the motivation strongly, also increasing the sense of unity but having less a strong effect on the transparency of the communication.

11.8 Evaluation of the STSD Workshop

The aim of the evaluation was to offer the project group the opportunity to comment and to assess the positive and negative aspects of the workshop and of the STSD module. The evaluation was performed after the workshop by means of an open discussion and a questionnaire that was specifically designed for the evaluation of the STSD module. Both sources of information are considered below.

The participative procedure allowed the participants to utilize their knowledge of the work environment, the joint input for analyzing the upcoming changes was considered important.

The criteria of the STSD module were considered interesting, allowing to view the work environment from a sociotechnical perspective. The criteria however were not always easy to comprehend, requiring the support of the workshop facilitator for further explanation. In addition, the time required for applying the criteria was considered too long.

The use of the criteria-objectives network for the evaluation of the new KLE concept was helpful, supporting a systematic approach for evaluating the changes. The changes on the objectives presented by the network coincided with the expectations of the workshop participants.

The project team agreed that the sociotechnical module is suited for analyzing and evaluating present or future changes of production at Volvo. For a regular use however, the module would need to be customized to the needs of Volvo. Once the 'users' would get accustomed to the procedure and the criteria of the module, it could be used on a regular basis for making systematic suggestions for improvements of work organization as well as for evaluating changes.

Important issues raised during this test were the company procedure and based on the evaluation outcome the rules needed for actually implementing suggested changes in production as well as the rules needed for the development process. Another issue was the importance of the workshop facilitator and which person at Volvo could take on that role and what prerequisites would be required for this role if the STSD module were used at Volvo.

11.9 Conclusions

Both the ergonomic and the sociotechnical modules were well received among the participants. They used the modules with great enthusiasm and showed an honest interest in discussing the issues covered by the modules. Both workshops showed the importance of a participatory process when considering ergonomic and sociotechnical aspects of the development process. The tools functioned as IT-based support for the discussions and proved to be very valuable to reach consensus and setting up priority lists for actions.

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12. Test at Finland Post

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Abstract. Within the PSIM project the concept and a software prototype of the E/S tool have been developed (Chapter 10). This chapter describes the test of the prototype of the E/S tool at the Helsinki Mail Centre of Finland Post. Two workshops one focusing on ergonomical aspects the other focusing on sociotechnical aspects were carried out for applying and evaluating the tool. In both workshops multidisciplinary project teams participated. The procedure and the obtained results of both workshops are described and discussed.

12.1 Introduction

12.1.1 The E/S Tool

One of the aims of the PSIM project was to develop software support for ergonomic and sociotechnical (STSD) analysis and design. For this the E/S tool (Ergonomics/ Sociotechnical tool) was developed (see Chapter 10). The E/S tool consists of different modules that focus on specific aspects of manufacturing systems. A central characteristic of the E/S tool is that it supports a participative approach therefore involving employees in the analysis and design process. The E/S tool is integrated in the PSIM environment and can be used in combination with existing enterprise software systems.

The four Ergo modules (see Chapter 9) of the E/S tool focus mainly on ergonomics in assembly processes. They help in the participatory process to describe, visualize and evaluate current and future assembly processes, work tasks, and workstations. They evaluate 1) process flow characteristics, 2) safety and environmental conditions, 3) physical load, and 4) mental load. They include a procedure and criteria for the evaluation of assembly workstations and processes, as well as a model for graphically displaying the structure of the process and the outcomes of the evaluation. Three-colour traffic lights visualize the unacceptably high risks in red, moderate risks in yellow, and insignificant risks in green.

The STSD module supports analysis and design of production systems focusing on the level of the individual and the level of the work group. On basis of the socio-technical approach (see Chapter 8) the module guides a multidisciplinary project team by means of visualizations and a flexible procedure in finding comprehensive solutions.

To prove the feasibility of the concept of the E/S tool and to evaluate its advantages and disadvantages the software prototype of the E/S tool (see Chapter 10) was tested at selected departments of the industrial PSIM partners. This chapter describes the procedure and the results of the test of the E/S tool at the Helsinki Mail Centre of Finland Post.

12.1.2 The Pilot Test Site of Finland Post

Finland Post Corporation is the leading messaging and logistics company in Finland. It is responsible for providing postal services and ensuring that these services are available all around the country. The Post conveys and delivers letters, newspapers and magazines, direct mail and parcels. In recent years the Post has vigorously expanded into the electronic messaging and corporate logistics sectors.

The Heavy Production of the Helsinki Mail Centre is part of Finland Post Production Services and was chosen as the platform for research and development within the PSIM project (see Figure 12.1). Half of the country's mail is sorted in Helsinki Mail Centre, which makes it the largest mail sorting centre in Finland. The Heavy Production handles about 70,000 bundles of magazines, newspapers, and direct mail and 50,000 maxi letters (bulky letters, small packets) daily.

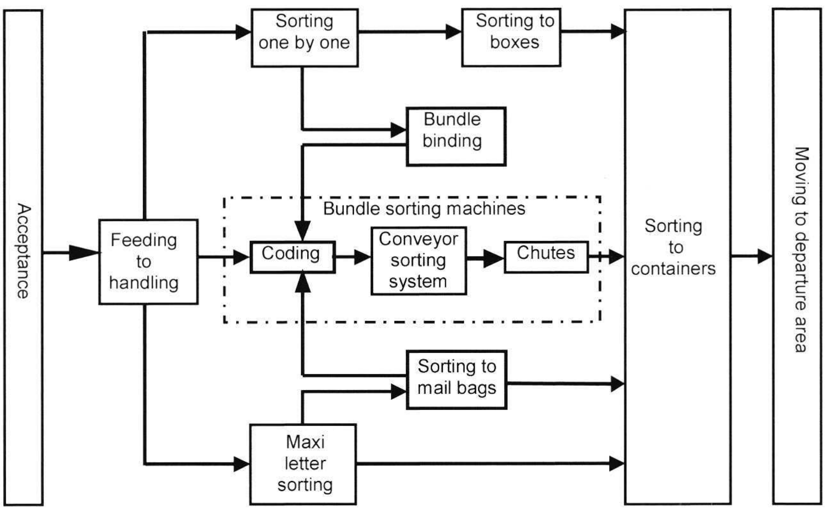

Figure 12.1 The Sorting Process of Heavy Production in the Helsinki Mail Centre

Bundle sorting takes care of sorting bundles to containers according to postal codes. There are seven work roles: organizer, feeder, coder, bundle repairer, chute sorter, forklift operator and supervisor. The work is done in two shifts of about 30 persons each. This unit receives input from the Acceptance (unsorted bundles) and gives input to the transport (sorted bundles). Based on previous observations the most serious ergonomic problems occurred in chute sorting. As the task was also diverse enough the E/S-tool test for the ergonomic modules was concentrated in chute sorting.

Maxi letter sorting (MLS) takes care of sorting maxi letters to containers according to postal codes. The following work roles can be distinguished in the process: feeder, rough sorter, fine sorter, forklift operator, wide letter sorter and supervisor. There are two shifts of about 15 people each working in MLS. MLS receives input from the Acceptance (unsorted maxi letters) and gives input to the transport unit (sorted maxi letters).

To test the STSD module of the E/S tool at MLS was inspired by the results of a personnel inquiry conducted by Finland Post. The results of the inquiry showed that work satisfaction was insufficient, that the number of multi-skilled workers was decreasing, and that job rotation was not executed sufficiently in the unit. The STSD module was considered particularly suitable for addressing these problems.

12.1.3 Aims of the Test

The test of the E/S tool had two aims: one aim was to develop solutions considering ergonomic and sociotechnical aspects for the selected production units, therefore providing Finland Post with suggestions and new ideas for optimizing their sorting process regarding the mentioned aspects. The other aim was to evaluate the E/S-tool application, eliciting strengths and weaknesses of the tool. For the test of the E/S tool two workshops were conducted: in one workshop the Ergo modules were tested, and in the other the STSD module of the E/S tool. In both workshops multi-disciplinary project teams participated. The project teams consisted of employees from different levels of the organizational hierarchy occupying different work roles. Both workshops were facilitated by a PSIM researcher, an ergonomics specialist and a sociotechnical systems specialist, respectively. The procedure and the results of the tests are presented in the following.

12.2 Test of Ergonomics Modules

12.2.1 The Procedure

A two day workshop moderated by ergonomics experts of PSIM was planned to analyse and find solutions to the ergonomic problems of chute sorting, guided by the Ergonomics modules of the software prototype of the E/S tool. People with different functions associated to chute sorting were invited to participate.
Steps performed before the workshop:

1. *Definition of the test site*: Chute sorting,

2. *Setting up a working group*: Workers at chute sorting, supervisor, production planner, designer, production manager, project manager,
3. *Collection of data*: Video recordings, photographs, data on handled items, drawing of the test area task descriptions.

The workshop consisted of the following steps:

4. *Kick-off of the workshop*: Presentation of the program, practical / organizational issues, presentation of the software modules,
5. *Evaluation of current situation using the four Ergo modules (process flow characteristics, safety and environmental conditions, physical load, and mental load)*: working in two groups with laptop computers,
6. *Prioritizing the problems*: Discussions in the groups supported by the red / yellow / green colour codes proposed by the E/S tool,
7. *Development of new solutions*: Evaluation of simulated new situations using the Ergo-modules,
8. *Final discussion and evaluation.*

The participants filled in a questionnaire (consisting of two parts) to evaluate the background for participative renewal, and the usability of the modules. The questions could be answered on a five point scale. The first part was filled in at the beginning of the workshop, the questions dealt with the possibility to participate in work place design. The second part was filled in after the workshop, the questions dealt with the usability of the modules.

The answers to the first part of the questionnaire showed that workers' possibilities to participate in development projects were regarded as rather low.

12.2.2 Results of the Analysis

Using the Ergo modules of the E/S tool the present situation was analyzed and the problematic tasks and working conditions identified. The chute sorting was divided into eight tasks carried out by the same worker.

In the *safety-and-environmental-factors* section one of the two subgroups considered chute sorting as one complete task set; the other considered each task separately. More than 20 hazardous situations were identified (4 red, 18 yellow):

- The hazard of slipping or stumbling because of loose bundle ties on the floor was regarded as the most frequent serious problem,
- The other two high risk hazards were associated with a space saving method to store two empty roller containers together in ‘doublets’, one lifted upside down inside the other. When undoing a doublet a container may hit the other or against the floor causing a hazard of high impact noise, and even a hazard of crushing some body part,
- Because of the overhead conveyor lines there is a hazard of objects falling from above because there are gaps in the safety nets under the conveyor, and bundles may fall on the worker under the conveyor.

The *physical load* session concentrated on pushing, pulling and lifting sections. The colour codes of lifting based on the NIOSH lifting equation were complemented by more detailed results of the equation from a simple Excel table. The test team worked in two groups, one analysed the odd-numbered tasks and the other the even-numbered. This limited test lead to 3 red marks, and 1 yellow mark. The basic work, sorting bundles into containers is heavy repetitive manual handling, extreme loads occur especially when placing bundles to the bottom of a new roller pallet in a stooped and twisted posture. High forces are also needed repetively when throwing items weighing up to 10 kg to the cages. Moreover, the workers may have to push stacks of bundles on a packed chute table which requires high muscular efforts.

Process flow was considered in one group for the whole chute sorting and in one group for each subtask. The analysis caused 3 red marks, and 7 yellow marks. The frequent lack of containers was regarded as an important reason for disturbed flow.

Due to limited time the *mental load* module had to be skipped over.

12.2.3 Derived Solutions

In the discussions eight problems popped up as having the highest priority. Each problem was then discussed in detail, and possible solutions were considered. Finally an implementation plan was created and one or more persons were named to be responsible for implementing each solution.

Many suggested improvements were instantly implemented, e.g. new trash bins with easier access were purchased to get rid of loose bundle ties, and the safety nets under the conveyor were checked and fixed for the gaps. There was some progress in all prioritized points before a follow-up meeting two months after the workshop.

12.2.4 Evaluation of the Test

Five participants answered the questionnaire on usability of the Ergonomics modules after the test. Quite high scores were given in answers to questions if the information seen through the tool was relevant (mean scores 3,2 - 3,8 in different modules), and if right problems popped up (mean scores 3,6 - 3,8, respectively). Somewhat lower scores were given to the questions: "Did the tool help in finding solutions?" (2,6 - 3,0), and "Did the tool lead to the results fast enough?" (2,3 - 2,8). As to the likelihood that solutions proposed, will be adopted in the production system, the participants were rather suspicious (the mean scores 2,0 - 2,4).

The Ergonomics modules turned out to be useful in guiding the discussion of the participative development group to essential improvements of work stations. But the modules could as well be used independently by different people to check ergonomic aspects of individual work stations.

Several suggestions were made on how to improve the tool further, e.g.:

- All the analyses are made on the task level, but some aspects of process flow or environmental factors should be analysed on workstation or even lay-out level,
- Analysis results (colours) and their comments should be automatically linked. The colour code alone gives too little information. The modification

of work station would be better guided if the tool would inform the participants of the most significant factors and of e.g. how 'red' the red is,
- The tool should be developed to allow the participative group to compare alternative solutions more easily.

12.3 STSD Module Test

12.3.1 Introduction

For the application of the STSD module prototype a three day workshop moderated by a PSIM member was carried out. Eight employees related to or working in MLS formed the project team for the workshop: Three mail sorters, one supervisor assistant, one supervisor, one production manager, one production planer and one project manager participated.

Previous to the workshop it had been decided (involving the project team) that the concept of Self-Managed Work Teams (SMWT) should be focused on as a possible solution for the problems at MLS.

12.3.2 Course and Result of the Workshop

As a first step of the workshop the project team agreed on specific problems of MLS that should be addressed. Problems had been collected previously to the workshop by the project team. The most important ones that were suitable to be addressed by the STSD module were chosen: the amount of operators and the volume of production do not match, the amount of multi-skilled operators is too low, job rotation is not executed sufficiently, the range of responsibility of the supervisor is too large and the Acceptance sometimes provides wrong items.

In the following the two phases of the STSD module procedure, the analysis phase based on the KOMPASS method [1] and the design and evaluation phase based on the IOR approach [2], are described as performed in the workshop at Finland Post.

Analysis Phase

The first step of the analysis phase is to define objectives that the solution to be developed in the design and evaluation phase needs to achieve. The STSD module provides four categories of objectives in order that the solution does not neglect relevant aspects: Business management, organization, employees and technology. After collecting and analysing the different objectives the following objectives were defined:

1. Better performance,
2. Increasing multi-skilled workers,
3. Better resource planning,
4. Improved cooperation with Acceptance,
5. Optimized work roles.

The objectives were prioritized as listed above. The objective 'better performance' therefore was considered the most important objective.

In a next step the current situation of MLS regarding the objectives was assessed. For every objective the project group had to rate the current situation of MLS. With help of this analysis it became clear for which objectives the situation was worse than for others. The result of this step is important for the design and evaluation phase in which it is possible to evaluate the effects of developed solutions regarding the objectives.

The objectives and the assessment of the objectives as well as the reasoning for the assessments were entered into the STSD module by the workshop facilitator.

For a better understanding of the STSD approach and the procedure supported by the STSD module some basic concepts were presented next. Furthermore, the purpose of the criteria used in the following step was explained.

Next, the criteria for the sociotechnical analysis were introduced and applied for the analysis of the current situation of MLS (the same criteria are used in the design and evaluation phase for evaluating solutions). All the criteria of the STSD module were applied (see Chapter 8 for the theoretical background of the criteria and Chapter 10 for the criteria implemented in the prototype of the STSD module).

The STSD module provides for every criterion a short explanation and a scale for rating the current situation. Together the project team had to agree on a common rating and a reasoning of the rating for every criterion. The result of this step was a detailed sociotechnical analysis of the current situation of MLS.

Next the criteria were related to the objectives. For every criterion the relations to the different objectives had to be defined. The result of this step was a simulation network connecting the criteria to the objectives. This network is central in the next phase for evaluating the derived solutions.

Design and Evaluation Phase

With support of the STSD module the concept of Self-Managed Work Teams (SMWT) was introduced. Advantages as well as disadvantages of the concept, points to be considered in designing SMWTs and examples of implementations of SMWTs were presented. The aim of this step is to provide the project team with a basis for developing one or several adaptations of SMWTs that fit the needs of MLS. The STSD module contains a set of questions that support the adaptation and concretion of SMWT to the demands of a specific situation. It has to be answered how the implementation of SMWT would effect the tasks and the roles of the different employees of MLS, if and how the process flow changes, which other organizational units need to be considered and what the expected advantages and disadvantages would be.

Supported by the questions two versions of SMWT were developed. For both versions it was assessed if and to which extent they improve the scores on the criteria compared to the current situation. These new criteria scores were entered into the STSD module and by means of the criteria-objective network the achieved changes on the objectives were visualized. Both suggestions had positive effects on all objectives. As the two suggestions were very similar one optimized version of SMWT was developed. Changes in the tasks of the operators are:

- The operators of the SMWT communicate directly with the bundle sorting unit, the Acceptance and the transport unit,
- The team members take on specialized roles (training of newcomers and of part time workers, maintenance, contact person for specific questions),
- If problems occur within MLS (including service and maintenance) the person affected by the problem contacts the 'specialist' within the team to solve the problem,
- The team takes on the responsibility for material orders,
- The SMWT votes a spokesman for representing the needs of the SMWT towards the supervisor and the management,
- An informal team meeting takes place every day at the beginning of the shift, the spokesman is responsible for the preparation,
- The spokesman receives from the planning unit a framework for a six week planning and is responsible for weekly resource planning, adaptations are executed in the daily meeting and consider job rotation.

Changes in the tasks of the supervisor are:

- The supervisor has less administration duties,
- Offers support for problems that can not be handled by team,
- The supervisor is not a member of the team,
- (S)he is the connecting link to the production manager,
- The supervisor participates in weekly/monthly meetings of the team to be informed on the current situation.

Changes in the process are:

- The items flow stays the same,
- Some responsibility from the Acceptance is taken on by MLS.

In general the developed version of SMWT assigns more responsibilities to the operators and allows the supervisor to focus more on coordination with other units and communicating with the management. Figure 12.2 contains the visualization of the effects of SMWT on the objectives presented by the STSD module in the workshop.

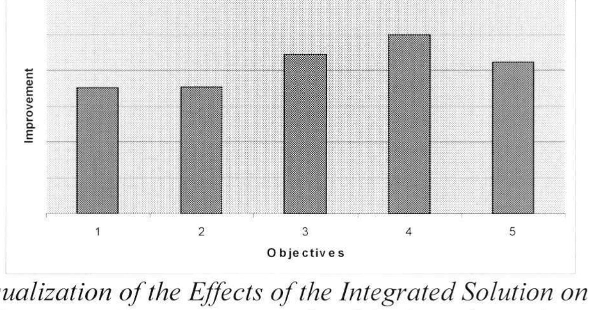

Figure 12.2 Visualization of the Effects of the Integrated Solution on the Objectives. 1) Better Performance; 2) Increasing Multi-Skilled Workers; 3) Better Resource Planning; 4)Improved Cooperation with Acceptance; 5) Optimized Work Roles

The solution has positive consequences for all objectives: It is expected that the resource planning is improved as the planning can be adapted more flexibly on a daily basis; by taking on new responsibilities and solving problems (if possible) autonomously the operators learn more skills; as the communication with the Acceptance is directly performed by an operator relevant information can be acquired easier and faster. Work roles are optimized as different operators specialize on certain aspects in addition to their 'normal' work and function as contact person for specific problems. By improved communications within MLS and with other units, and by optimized roles of the operators and increased flexibility it is expected, that the overall performance (speed and quality of the sorting process) is improved.

12.3.3 Evaluation of the Test

The STSD module and its application were evaluated by the project group at the end of the workshop. The aim of the evaluation was to offer the project group the opportunity to comment the workshop and to assess the positive and negative aspects of the workshop and of the STSD module. The evaluation was performed by means of an open discussion and a questionnaire that was specifically designed for the evaluation of the STSD module. The summarized results below consider both sources of information.

The procedure supported by the STSD module was considered transparent and well structured. It was very suitable for approaching the problems of MLS and allowed to process a lot of information in a short time. It was mentioned however, that the step of introducing and applying the criteria was too detailed and therefore required too much time. Nonetheless this step was considered interesting, providing insight into the complex relations between sociotechnical design criteria and the defined objectives.

Regarding participation aspects it was stated that the participants were able to utilize their specific knowledge of their work environment for analyzing the situation at MLS and developing the solution. The workshop provided a very good basis for the participants to communicate with colleagues from different levels of the organizational hierarchy performing different functions, and for being involved together in a decision process. It was also stated that the participants profited from the knowledge of their project team colleagues and that the role of the workshop facilitator was important for supporting the workshop.

According to the project group the relevant problems were addressed and their involvement was considered essential for developing the solution. It was clearly stated that involvement in further changes of the work environment is desired.

From a sociotechnical point of view the evaluation showed that human and organizational matters were considered very adequately, technical aspects needed less consideration. Due to set constraints technical aspects were less within the focus of the workshop. The application of the criteria as well as the criteria-objectives network helped to make relations between different aspects within MLS transparent, especially the relations between organization and the individual tasks. It was stated that more visualizations would facilitate the comprehension of the sociotechnical concepts and of the criteria.

The adaptation of SMWT to the needs of MLS was considered a realistic solution for addressing the problems and reaching the defined objectives. During the process of developing the solution critical objections helped considering relevant aspects and allowed developing a solution that integrated the different points of views of the participants.

12.4 Discussion and Conclusions

The two workshops showed that the E/S tool was well suited for addressing the relevant issues at Finland Post. The tool gave answers to questions related to specific task characteristics of operators (and supervisors) as well as to questions related to work organization. The employees participating in the tests were motivated and offered important input for the reorganization processes, showing the advantages of the participative approach. The tests however also showed where the different modules of the E/S tool need improvement.

About 30 people at different organizational levels of the Helsinki Mail Centre have been directly involved in the PSIM project, and many more in the background not directly related to the tests. The project has been well recognized due to visits of PSIM researchers and articles in personnel magazines. Participation in the PSIM project has inspired discussions on ergonomic and sociotechnical issues, and encouraged people to present their ideas and finding solutions for problems.

The indices of the yearly personnel satisfaction questionnaire of Finland Post in 2001 showed improved figures after a decline of several years, especially as regards the personnel of Heavy Production. Better chances to participate in work place renewal opened by the PSIM project, and the concrete implemented solutions for daily problems, explain some of the improvement.

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13. The Fiat Pilot Site

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Abstract. In this chapter the history and the main characteristics of the PSIM environment application at the CRF test site will be described. After few words about the history and the context in which the study was developed, the relevance of the case study will be described, as well as why this particular case was chosen by Fiat to be developed at CRF. Next follows a detailed description of the benefits to be gained by implementing a PSIM environment in the modelled situation in the case study.

13.1 Introduction

The case study addresses the Design Process, a part of FIAT Auto core process Product Development Process (see Figure 13.1), interacting with many other main company processes (see Figure 13.2).

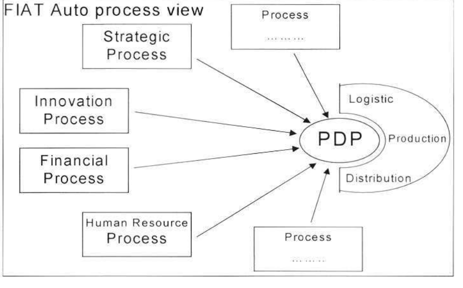


Figure 13.1 FIAT Auto Process view

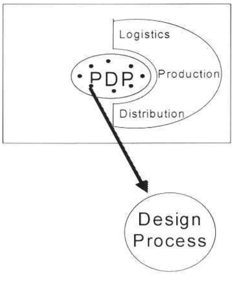


Figure 13.2 Design Process as Part of the PDP

At first sight it might not seem a very logical choice to use this particular case study when developing a participative simulation environment for enterprise renewal. This is because the PSIM project was originally meant for application in a manufacturing environment. And this case study is concerned with a design process. However, the case study does have elements in it, which give it a potential value for use in such an environment. This is because the case is concerned with throughput and the possibility of rework. Rework in the context of automobile design is not so much concerned with rework in the literal sense, but with modifications made in the design which also affect other design steps and require the development process to return to an earlier phase in the process. The case study clearly represents the way in which product modifications are managed in the present situation and can easily be modelled. As is shown in the next section, there are some procedures in the present way of working where the techniques that are offered by a PSIM environment could yield significant results. The field of modification management in the case study could also be expanded to include process changes, as it now contains only product modifications.

13.2 The 'As Is' Situation in Fiat Pilot

At FIAT Auto a standard procedure for car design is used, which is called New Process of Product Development (NPSP). This process is divided into several phases as shown in the Figure 13.3.

Figure 13.3 Phasing of the FIAT Auto's Design Process

A new car design process runs from phase 1 to 'n', starting at time '0-M' (the initiative starting point) and ending at time '0' (the new car launch). In the final part of each phase, modifications (see Figure 13.4) to both the product and the process (not very common) may have to be managed. Modifications management enhanced support is an essential added value coming from PSIM environment functionalities.

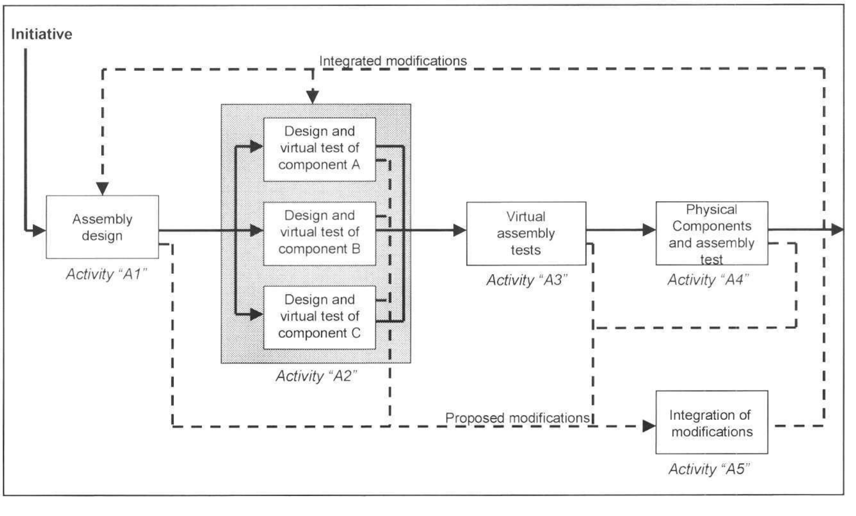


Figure 13.4 Design and Testing of an Assembly

The above figure models a simplified archetype of the design process (the final product is supposed to composed of three main subsystems – engine, body and wheels – referred to as components A, B and C) and each design activity is characterized by certain fundamental parameters:

- *A throughput time*: the minimum time to successfully complete the activity,
- *A rework time*: determined on a learning curve basis, is inversely proportional to the number of reworks meanly necessary to successfully complete the activity,
- *A probability of success/failure*: a binomial distribution for each activity.

As for a real-world example, dealing with true complexity of a car design implying the detailed description of all its relevant subsystems and of the corresponding design processes, it would have gone too far for the project objectives, the case study is an archetype meant to give a global indication of costs and is not meant to model real complexity. Nevertheless, due to the methodological approach, the model can be easily expanded to match real-world, by detailing step A2, with as much subsystems as necessary to model the full complexity of the design of a car. By a recursive approach, models underlying each subsystem in step A2 may be defined to fit subsystem complexity by splitting it into its components. All that may be done by *underlying* the basic model presented here, without changing the basic model itself.

Another relevant aspect is the number of hierarchical levels involved in the acceptance of modifications due to the three teams involved in the design of a car. At platform level (the level concerning all cars of a certain class), there is a *core team* with a *Model Responsible* heading the *core team* of each new model. He is not only responsible for its model design, but also for its relations with other models in the same platform. The other core team members are the *System Responsibles*, each one heads a *project team* dedicated to the design of one subsystem of the car. Inside a project team there are several *Team Leaders*, heading *component teams*, each one dealing with the design of one component of the subsystem, supported by *Performance Engineers*. With this structure it is a long way to modifications, see Figure 13.5

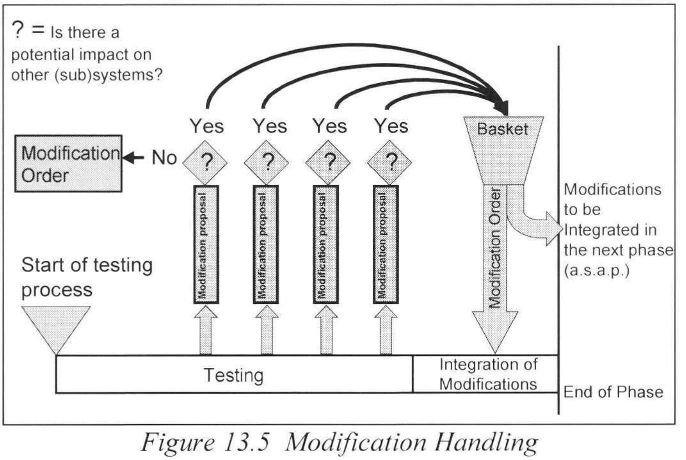


Figure 13.5 Modification Handling

- When an *experimenter* detects an anomaly in the product at component level reports it to the *performance engineer*,
- The *performance engineer* reports the anomaly to his team leader who makes a *Modification Proposal*,
- The *team leader* verifies with the *system responsible* whether the change influences other components or subsystems,
- If not the modifications can be accepted without problems and a *Modification Order* is issued,
- If yes, the proposal is put in a 'Basket' together with other proposals that will all together be integrated into the design at the end of the phase,
- 'Integration of modification' represents the last step of this phase where all *Modification Proposals* are assessed together at core team level by the *system responsibles* and the *model responsible* and integrated into the design. The responsibility for this step lies with the *system responsible*, but *team leaders* and *performance engineers* also make a contribution.

It is important to keep in mind that the figure above is only valid for anomalies detected at the lowest (or component) level. If an anomaly is detected at a higher level the change proposal is made from there and the change is also enacted from there. Who is responsible for which step in the design process is shown in Table 13.1 below.

Table 13.1 Roles and Responsibilities for Each Activity

Activity	Description	Actor	Role
A1	Assembly design	System Responsible	Responsibility
A2	Design and virtual test of the component	System Responsible Team Leader Designer	Supervision Responsibility Execution
A3	Virtual assembly test	System Responsible Team Leader Performance Engineer CAE Expert	Supervision Responsibility Responsibility Execution
A4	Physical components and assembly test	System Responsible Team Leader Performance Engineer Experimenter RUS RPA CS	Supervision Responsibility Responsibility Execution Contribution Contribution
A5	Integration of Modifications	System Responsible Team Leader Performance Engineer	Responsibility Contribution Contribution

As can be seen in the table, many roles are fulfilled in each step by the mentioned participants. Each 'responsible' can detect an anomaly and issue a change proposal, which is then passed further through the hierarchy. Also, some actors are mentioned in the table that have not been mentioned earlier. Those are external actors in the project, they will not be elaborated on.

As is described above the modification process goes through many levels and it takes a long time before a change proposal made at a relatively low level is enacted, decision-making is too high up in the hierarchy and the performance engineer has little influence in the implementing of his modification:

- There is a hierarchical information exchange, where information passes through all levels with slow and time-consuming decision making,
- The impact of a decision is assessed solely using personal judgement. The System and Model Responsible make the ultimate decision based on their own experience and insight. Although this could be an accurate means of decision-making it might be a good idea to have some sort of decision-support system to support an accurate analysis of the impact of proposed modifications,
- There is little sharing and exchange of knowledge. Because of the central level at which the decisions are made only a few people have a broad picture of the problems encountered and the modifications made in a phase,
- This is of particular interest if the number of participants involved in each phase is considered. It is important that all the actors that need to know about the modification order are told. In the present situation this is done, but the procedure is far from optimal as those issuing the order have to assess who could need the information and make sure that they receive it.

In the followings it will be shown how PSIM can help to overtake this difficulties.

13.3 PSIM Support to the Renewal Process

It is in the modification procedure discussed above that renewal and improvement can be achieved by introducing a PSIM environment whose goal is (as stated in Deliverable 1.3) *"to allow employees to develop suggestions for organizational renewal by means of simulation considering technological, organizational and human aspects."*

The implementation of a PSIM environment may (in the long term) create an environment in which decision making is done at the level at which the anomaly is detected, thus increasing employee involvement (if you encounter an anomaly you can try to find a solution by yourself, instead of passing the problem on to your superior). It also has the potential to speed up decision making by eliminating time consuming, hierarchical decision processes, but this, too, is a goal that will require middle term organizational changes: this work renewal and strategy can not be imposed on people 'overnight'. People have to grow accustomed to the new way of working and gradually change their own patterns.

But, since now, the quality of decisions can be improved by the simulation possibilities offered by a PSIM environment. If a possibility exists to simulate the impact of decisions and possible improvements, the improvement value of the decision can be ascertained. It would then also become possible to further refine the proposed improvements and either increase the related benefits, or to discard the proposed change in an early stage with reduced cost and time consequences.

Another point to mind is the difference between a *product improvement* and a *process improvement*. The modification process in the case study is meant explicitly for handling product improvements and redesign design steps. PSIM environment in

Fiat pilot achieved both goals: enhance product improvement as well as enterprise renewal through the structured implementation of process improvement proposals that can be made at *all* organizational levels.

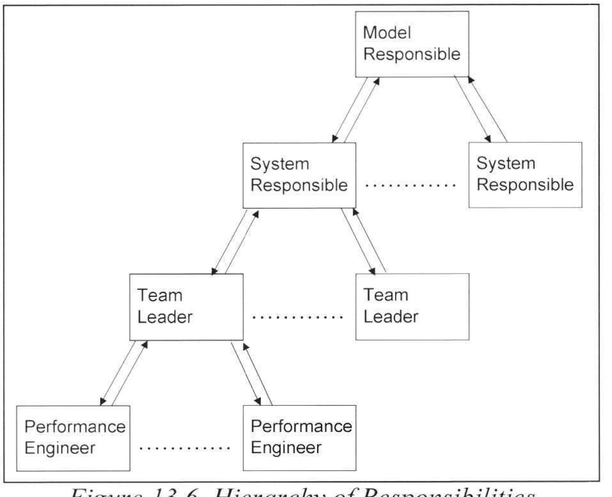


Figure 13.6 Hierarchy of Responsibilities

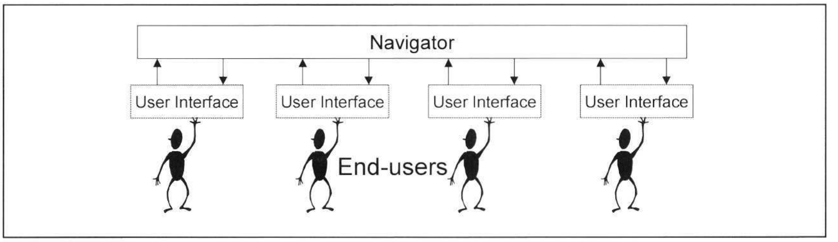
Figure 13.6 is meant to once again demonstrate the number of levels involved in the decision-making process. But it also shows the lack of knowledge sharing in the modification process. Knowledge is shared in a top-down way, but not horizontally: a performance engineer is not informed of improvement and innovation ideas coming from another performance engineer, other than by informal, unstructured information. By this approach, just product modifications may be properly managed as, due to the division into well defined subsystems, only people dealing with elements affected by the suggested change need to be informed.

To encourage process improvement and to support integral enterprise renewal it is important that information, proposals and ideas can be shared and cross over the whole organization. PSIM environment can help achieving this goal.

By means of the Navigator functionalities, cross communication procedures may integrate actual hierarchical ones: each worker (at whichever level in the organization) will access and provide information, guided and supported by a customized procedure and user-interface (see Figure 13.7).

By this way, PSIM environment will support the company in both *operating* and *renewing*, that is supporting both *on line operation* (in this specific case *product design*) and *strategic operation* (that is *company design* - looking for better ways to operate).

By Navigator functionalities, PSIM will provide an environment in which actors at any level and in all sectors of the company are enabled to profitably contribute to the conception and implementation of product/process improvements and enterprise renewal. In the Fiat pilot, this means supporting the improvement of the final product, of the manufacturing process and of the design process of both, by cutting out the hierarchic constraints to information, no longer limiting its flow to those directly involved, but being able to integrally involve all actors into an integrated, under-



Figuur 13.7 The PSIM Navigator

stood, and therefore shared, improvement and renewal process. All that by means of an efficient, safe, user-aimed environment. This means that every user gets the information he or she needs at that specific moment, in a format he/she is confident with.

13.4 Conclusions

From PSIM application, both short-term, tactical and long-term, strategic goals are forecast at FIAT Auto.

Several improvements directly affect current design process, enabling modification time reduction by a more efficient and effective management of changes, cost control by earlier and better evaluation (eventually by simulation) of technological solutions, and knowledge capitalization by a clever knowledge management approach.

In the same time, PSIM may support achieving most goals that fit into the long-term strategy of FIAT, that are:

- *Time to market reduction.* As product modifications are handled faster and the process is constantly improved by suggestions from the 'workforce', the whole design process will take less time. This is very important to help FIAT gaining and maintaining a competitive edge towards its competitors.
- *Process and product quality Improvement.* Modifications are handled better and faster and actors are given a chance to provide suggestions for a better way of doing things. In the long-term, this should lead to an optimized design process at FIAT Auto, but also to a better-designed car.
- *Costs reduction.* For the introduction of a PSIM environment some costs will be made. These costs will however not be very high, as most of the users will already have compliant hardware on which the developed software can be run. Other costs will be involved in the instruction of users in the operation of the Navigator tool. It can, however, be expected that these costs will outweigh the benefits gained by the implementation of a PSIM environment. These cost reductions are directly involved with the more efficient and faster way of working described in the sections above.

14. Test at Ford

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Abstract. This report describes the test of the Ergotool module of the E/S tool and the participative procedure performed at the Final Assembly shop of the Wayne plant at Ford Motor Company, Michigan, USA. Three stations were selected, videotaped, measured, and evaluated according to the Ergotool and evaluated in the participative procedure. The test was very successful. Several cultural and/or company differences could be seen especially compared to Volvo Cars. The fixed organization at the shop floor with no rotation or work enlargement in combination with the very strong focus on mass production and actual costs was the main differences that influenced the usage of the PSIM environment. The PSIM tool and procedure could be used at the Wayne plant but this case study pinpointed the importance of making them possible to implement in a flexible and easy to adjust way. In addition, Ford and the Wayne plant was given an example of how ergonomic issues can be treated in a participatory way and what benefits rotation and work enlargements can give on ergonomic aspects.

14.1 Introduction

This report describes the test of the Ergotool module of the E/S tool and the participative procedure performed at the Final Assembly shop of the Wayne plant at Ford Motor Company, Michigan, USA.

The objective of the test was to generate ideas for improvements in efficiency and health of a part of an assembly line at Ford in the area of ergonomics. A complementary aim was to evaluate the ergotool and the participative procedure in a company belonging to the American culture.

Ford Motor Company, the owner of Volvo Cars Corporation (one of the PSIM partners) was willing to participate in this study with the goal to compare and learn about ergonomics in Europe and at Volvo Cars. The Wayne plant was selected because it was one of few plants where the union had two ergonomic representatives working full time with ergonomic issues. The ergonomic work was carried out in well-organized LEC meetings with a tremendously interested workforce and several good results had been reached.

The Ergotool test at Ford focused on the module physical load. The other modules, safety, mental load and process flow, were demonstrated to the working group, but not tested.

14.2 Test Site Description

The car produced in the Wayne Plant was Ford Focus 4-door Sedan & Combi Coupé. The Wayne Plant produces about 450 000 cars per year at a line speed of 78 cars per hour, two shifts per day.

The Focus had been produced at the Wayne plant for about two years so the production was in a stable condition and no major changes was taking place at the time of the study.

The plant was originally built in the 1950s. New equipment and tools had been installed several times since then, but most of the equipment present at the line today was from the introduction of the Escort in 1989 as no major modernization was made due to the change of models.

14.2.1 Organization

The Factory was divided into 4 areas/shops: Stamp, Body, Paint and Assembly, and has support functions such as Manufacturing Planning, Plant Vehicle Team, Quality, Control, Human Relations, Material Planning & Logistics.

The final assembly plant was divided into two areas, which were managed by a superintendent. Each area was further divided into Zones, 12 zones in total. Each zone had approximately 65 operators employed. Each operator has his own job which he repeats app. every 50 second. Normal working hours is 10 hours a day (8 hours plus 2 hours overtime is normal), 5 days a week. No rotation or 'long jobs' existed. Vacancy replacements and relieve men were used in case of absenteeism.

In the Final Assembly there were 15-20 different job classifications, specified in agreements between the operator and the Plant. Each class requires different qualifications and pays wages accordingly. This makes rotation between jobs impossible. The plant had several different unions and thereby different union agreements regulating the work organization. The Final Assembly had an 'old' agreement while the Stamp & Body shops in the same plant had a modern agreement.

The union was very strong and had a strong influence especially on ergonomics. At the Wayne plant there was a local agreement that in addition to the national agreement supported two Health & Safety and two Ergonomic Representatives. Ford Motor Company paid all of the Union representatives.

To work for a Ford plant was generally considered 'good work' and there were always people in line for work. Wages in the Final assembly were approximately 25$ per hour, up to 100,000$ per year (a little higher in the Body shop, 26$ per hour). Normal work hours were 6:10 a.m. - 4:00 p.m., 10 hours every day, if no reason for low production exists. Overtime is considered normal and can not be turned down, but is paid 1,5 times the money. It is also mandatory to work 6 weekends, if required. Extra hours can be taken out as spare time.

14.2.2 Ergonomics at the FORD Wayne Plant

A large spectrum of ergonomic activities was taking place at the Wayne plant. During the short time present only an overview of the activities in the final assembly shop could be captured. A short summary of these activities is presented below.

The ergonomic evaluations are mainly performed on problem stations and are initiated by complaints from the operators or by statistics of hospital calls. The union ergonomic representatives or the health & Safety representatives mainly perform the evaluations made today at the Wayne plant. Capturing problem areas is done by the ergo representatitives (or health and safety representatives) by discussion with the operators at their workstations. The problem points and possible solutions are then forwarded to a multifunctional group; Local Ergonomic Committee (LEC), where negotiation about actions required and costs takes place. Each possible investment has to be strongly motivated from a cost/benefit perspective. Actual costs and emergency calls to the hospital are at focus and dealing with proactive actions and possibilities of injuries to occur has been problematic so far. The LEC had the power to stop a very bad solution from coming on future car models in the plant (NO BUILD). But so far they had no cooperation with the manufacturing engineering concerning new car models early in development phases. Most ergonomic remedies and projects were paid from a found owned jointly be the Union and the Company.

Several tools are used for performing the evaluations. Except for practical tools such as weight and force measuring of tools, also software tools for the actual analysis were used. A Ford-developed tool called ErgoPlus, implemented on the Intranet was used for different kinds of physical load evaluations. The ErgoPlus was a combination of several well-known standards and tools such as Niosh and Rula. The problem areas found were then documented in a computer-based program called ErgoRX. The ErgoRX was newly developed and had the purpose of documenting problematic stations to use as 'lesson learned' for future projects.

There is no implemented procedure for scanning all stations from an ergonomic viewpoint and thereby no evaluation record of every station.

14.3 Test Procedure and Implementation

In order to make this test several preparatory actions were taken by both PSIM participants and the Wayne plant. A preliminary definition of the stations of the assembly line to be evaluated and setting up a working group to be involved in the test had been carried out prior to the actual test.

During the introduction day of the test several presentations about PSIM, Volvo, TNO and Ford were made and questions and discussions were frequent.

At the test site the selection of stations to study was revised due to the present situation. Three stations were selected, videotaped, measured, and evaluated according to the Ergotool.

14.3.1 Selection of Stations

The following three workstations were selected:

- Hanging on doors,
- Tire station,
- Muffler station.

The station hanging on doors was selected because a similar workstation at Volvo Cars had been part of the Ergotool test, as well. These two stations at Ford and Volvo could then be compared.

The second station (tire station) was selected because it had just been improved and it would be interesting to show the outcomes of the Ergotool concerning this workstation.

The third workstation was chosen because Ford wanted this station to be analyzed. This station had a high priority at Ford to be improved because of many ergonomically problems.

14.3.2 Video and Measurements

At every workstation two ergonomic experts performed the following activities:

- A video was taken of operators performing their tasks/job. Movements, postures and all activities were all recorded, several times,
- Weight of parts and tools were measured,
- Forces (pulling and pushing) were measured,
- Distances (walking, reaching etc.) were measured.

Operators were asked to do their job as they usually do.

14.3.3 Evaluation of Workstations

Every workstation was analyzed with help of video, the measurements taken and the Ergotool. First, the tasks performed at every workstation were listed in the Ergotool. In the next step, every task was analyzed with respect to physical load. This was done in the Ergotool using the video for analyzing posture, task time, and frequencies. Data from the video and from other measurements were entered into the Ergotool. Risks concerning physical load were made. Ergonomic experts from TNO & Volvo made this analysis, the Wayne plant ergonomic representatives were not involved.

14.3.4 Procedure of Group Sessions

The procedure tested at the Wayne plant was the participative part of the tool specific PSIM procedure. The aim of the procedure was to gather all parts with interest in the specific ergonomic issues to be analyzed. The procedure used for the group session was in line with the general PSIM procedure.

After filling in the Ergotool, a program was made of the group session, concerning steps, time schedule and participants. Participants were invited: operator(s), FPS co-ordinator, ergo & health and safety representatives, union representative, manufact-uring engineering (Plant Vehicle Team, responsible for smaller product changes and process-related changes), Ergonomic Engineer (development organization, responsible for ergonomics in new car projects/large changes to the existing car into a plant).

The procedure of the group session was planned as follows:

- *Introduction of participants*: who is who and what function,
- *Introduction to the session*: aim and program,
- *Video presentation of the job*,
- *Inventory of tasks on the flipover (paper)*,
- *Inventory of problems on the flipover with help of the video*: Ergonomic problems and other problems. Participants were asked to present any kind of problems they could think of in relation to the station,
- *Discussion on the problems*,
- *Inventory of possible solution*: Participants were asked to choose most important problems and to come with any kind of short-term solutions and long term solutions,
- *Showing results in the Ergotool*: Ergonomic risks were showed using the Ergotool.

These activities were performed three times in three group sessions, one for each workstation: hanging doors, tire station and muffler station. Two ergonomic experts were facilitating the session.

14.4 Ergonomic Results

In the following section the results from the expert evaluations with the ergotool is presented for the three stations selected followed by comments, further problem definitions and possible solutions discussed at the workshop session.

14.4.1 Station 'Doors On'

The first station to be analyzed was the 'hanging on doors'. One operator hanged each of the four doors.

At the *door station* the following activities were observed as well as identified by the working group:

1. Getting the lifting tool,
2. Fetching the door,
3. Moving the door-and-lifting tool to the car,
4. Attaching the door to the car,
5. Assembling the electrical cable,

6. Hanging the door onto the hinges,
7. Fastening the electrical cable,
8. Hand start the screws,
9. Fastening screws with power tool,
10. Removing the lifting tool,
11. Handling the lifting tool.

These tasks are performed for eight to ten hours a day.

Both the group and the ergonomics identified the following problems, see Table 4.1, as a physical load problem, with the problems in bold being the most severe according to the worker.

Table 14.1 Identified Problems at the Doors-On Station

Tasks/Activity	*Physical load problem*	*Remarks*
Getting the lifting tool	Pushing and pulling	Tall person can hit his head
Fetching the door	Pushing and pulling, sometimes manually lifting (20 kg) because door gets stuck on carrier	Maintenance problem. Causes physical and quality problems Possible solution: maintenance?
Moving the door + lifting tool to the car	*Pulling. Lifting tool is heavy*	Possible solution: Redesign tool (like Volvo tool?)
Attaching the lifting tool to the car	Twisted/lateral bending trunk	Clamp: too much pressure on car
Assembling the electrical cable	Twisted/lateral bending trunk	
Hanging the door onto the hinges	Static posture: twisted/lateral bending, pushing, Lifting door to hinges	There is not enough pressure to fetch door from fixture. Doors are not fitting properly (quality?)
Fastening the electrical cable	Bent wrist. Twisted/lateral bending trunk	Little room to fasten cable/wire. People get restrictions (hospital). There is no proper tool Possible solution: in product design?
Hand start the screws	Twisted/lateral bending trunk	
Fastening screws with power tool	Torsion moment in wrist and arm; twisted/lateral bending trunk	Air tool gives too much torque
Removing the lifting tool	Pushing	
Operating the lifting tool	None	Handle and buttons are ok

During the group session the operators added some general problems: The work area is too small and there is too much people traffic.

According to the Ergotool (guidelines) some additional risks were considered:

- Pushing and pulling the lifting tool. An initial force of 80 N was measured in one direction. Pulling with whole body (8 kgf) is identified as green. Pulling the door with only two arms (not a whole body activity) will be yellow when the force exceeds 8 kgf and red when it exceeds 14 kgf. Force for turning the lifting tool could not be measured, but was estimated to be much higher: at least 16 kgf. As the worker identifies pushing and pulling lifting tool and door as a problem too, this workstation could be improved by redesigning the lifting tool. Volvo recently developed a new (light) lifting tool,

- Possible risks (safety) due to moving doors into the workstation,
- Working posture: twisted and lateral bent trunk during mounting the door to the car. Body weight is mostly on one leg. Risk is identified as red because the summed task duration is more than 4 hours (8-10 hours). The moving 'platform' in this station has improved the situation as much as possible; operators do not have to walk alongside the car. There is not a platform like this at Volvo. Still the working posture at this station is twisted,
- Twisted and bent neck while mounting the door. Risk is identified as red because the summed task duration is more than 4 hours (8-10 hours),
- Torsion moment in wrist and arm while using the power tool.

In conclusion this station would be marked as red in the Ergotool.

14.4.2 Station 'Tires On'

The second station to be analyzed was the 'tires-on' station. One operator was putting on both front and back tires.

At the *tire station* the following activities were observed as well as identified by the working group:

1. Fetching/rolling the tire,
2. Putting the tire on the pins,
3. Using tool to hold the tire,
4. Assembling the nuts (with a tool).

These tasks are performed for eight to ten hours a day.

Table 14.2 Work Session Identified Problems at the Tire Station

Tasks/Activity	*Physical load problem*	*Remarks*
Fetching/rolling the tire	None	Workstation has been improved. No carrying or lifting
Putting the tire on the pins	None	
Using tool to hold the tire	None	
Assembling the nuts (with a tool)	None	Sometimes: twisting fingers

No major problems were identified by the workers, as seen in Table 14.2. There was only one single remark: sometimes rubber is coming off the tires (dirty).

At the *tire station* a few possible risks were considered with the help of the Ergotool:

- Forward trunk bending (0-20°) for more than 4 hours: green,
- In some cases arm elevation during mounting tires. Only when operator stands straight there will be some arm elevation. Instructions will be important,

- Pushing with hand and arms. It was not possible to measure forces. Frequency is 156 times per hour (2 tires per car), task duration is 10 hours, pushing on elbow height will identified as yellow when the force exceeds 8 kgf and red when it exceeds 14 kgf.

In conclusion at this improved station there is no lifting or carrying anymore (green). Trunk bending is (0-20) also considered green. Arm elevation (20-60) depends on personal working method: some operators elevate the arm, some operators don't (green/yellow). Risks of pushing are not considered, as forces could not be measured.

14.4.3 Station 'Muffler On'

The third station to be analyzed was the 'assembly of the muffler'. The muffler was picked up and assembled in one piece, by one single operator. For connecting it at the front assistance of another operator is needed.

At the *muffler station* the following activities were observed as well as identified by the working group:

1. Taking muffler from the packaging,
2. Carrying the muffler to the car,
3. Holding muffler while waiting,
4. Lifting muffler to the car,
5. Mounting the muffler on to suspension,
6. Fastening two clips in the body,
7. Moving the dividers away,

These tasks are performed for eight to ten hours a day.

Both the working group and the ergonomics identified physical load problems (see Table 14.3), with the problems in bold being the most severe according to the worker.

At the *muffler* the following possible risks were identified with the help of the Ergotool:

- Lifting muffler (15 kg) from racks in bent posture, 78 timers per hour: Red,
- Carrying muffler (15 kg) over 4-8 meters (on shoulder level), 78 times per hour: yellow,
- Lifting muffler above shoulder/head level with two persons, 78 times per hour: red,
- Arm elevation > 90 °, summed task duration > 4 hours a day: Red,
- Some possible safety risks.

Table 14.3 Identified Problems at the Muffler Station

Tasks/Activity	*Physical load problem*	*Remarks*
Taking muffler from the packaging	**Lifting (15 kg) in bent posture (78 times per hour): Red**	Muffler sometimes stuck in the racks Wrong muffler is picked because of wrong ticket, then another muffler must be picked up
Carrying the muffler to the car	*Carrying (15 kg) over 4-8 meters. Yellow*	Too many racks spread out
Holding muffler while waiting	*Carrying*	Operator has to keep up with the speed and has to wait for other operator
Lifting muffler to the car	Lifting (15 kg) with two person above shoulder level: Red	
Mounting the muffler on to suspension	Lifting (15 kg) with two person above shoulder level: Red	
Fastening two clips in the body	Arm elevation >90°, summed task duration >4 hours a day = red	Sometimes rubbers are missing
Moving the dividers away	None	

During the group session some ideas for possible solutions were discussed:

- Muffler in two pieces? (reduces weight),
- Tool to lift/hang one end of the muffler first,
- Lifting tool,
- Job enlargement,
- Indexing machine: muffler is delivered on working height, next to the work-station,
- Rubbers could be mounted at the muffler station.

In conclusion this station was evaluated as a high-risk station due to many reasons and turned out very red in the ergotool.

14.5 Evaluation of the Software and the Procedure

The evaluation was made mainly by the union representatives and the Ergonomic Engineers together with the PSIM testers.

14.5.1 Procedure

The general conclusion was that the procedure brought a lot of good aspects such as involving the operators and has all stakeholders present at the same time. The procedure that gave a lot of new information, especially from the operators as direct comments reached the engineers without any in-between info carriers. Especially interesting was also the discussion about several other problems such as quality and maintenance that was brought up because they seemed to be connected to the ergonomic problems. These problems had earlier been put forward through different channels for different reasons, but could here be connected to ergonomic problems.

However this works fine in theory, at the Wayne plant it was very hard to gather those people for one occasion and it will be almost impossible to do it on a regular basis. The worst part is to take the operators from the line for a longer period that 30 minutes. That requires great planning and can be subjected to change due to whatever production problem that comes at hand. The work organization and the culture at the Wayne plant make this kind of procedure very hard to perform.

For very specific occasions however, this could be a possible procedure. Examples of such situations are major changes or severe problems where no solutions have been found.

A suggestion that was made due to the above comments was a procedure with shorter sessions with the operators to collect their view of the problems, and then continue without operators. When one or several solutions are found, another session with the operator can take place to give feedback and get comments on the solution.

14.5.2 Ergotool

The general conclusion was that the Ergotool could be useful in a procedure that fits the organization. The analysis provided were relevant and the figures and border values did correspond to a large extent to what was used at Ford.

Some following suggestions for improvements were made:

- The software/interface must be easy to use,
- The tool must show why a task gets red. The guidelines should be incorporated in the Ergotool,
- Input parameters as well as the outcome ('borders') must be well defined for the user,
- The tool must give feed back which factors are critical: for instance during lifting: horizontal factor or weight is critical,
- The tool must be useful for evaluation during product design and production.

In general, a tool for detecting and selecting stations or jobs with high potential of ergonomic risk was searched for. A tool that could help with what actions that should be taken after the analysis would be of great assistance at Ford in combination with the ErgoPlus tools that are used today.

14.6 Conclusion

In conclusion, the test was very successful. It gave Ford, Volvo and the PSIM project (as representatives from the EU community) a possibility to exchange knowledge about dealing with ergonomic issues. Several cultural and/or company differences could be seen, especially compared to Volvo. The fixed organization at the shop floor with no rotation or work enlargement in combination with the very strong focus on mass production and actual costs were the main differences.

Ford and the Wayne plant was given an example of how ergonomic issues can be treated in a participatory way and what benefits rotation and work enlargements can give on ergonomic aspects. Several study participants at the Wayne plant also became aware of a wider range of problems at one of the stations (doors on) as well as the connections to the ergonomic problems reported earlier.

The PSIM tool and procedure could be used at the Wayne plant but this case study pinpointed the importance of making them possible to implement in a flexible and easy to adjust way. The values used in the tool as well as what to highlight as red, yellow and green must cooperate with the company procedures and policies of making remedies. Also, the participatory procedure must be able to adapt to the company situation as well as existing committees and tools. In this case, make the operator involvement shorter in time and thereby more focused.

Acknowledgements

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15. Test at Yamatake Control Products

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Abstract. Yamatake Control Products (YCP) provided the PSIM project with a pilot test site in Japanese electronics industry. In the beginning of the project the European PSIM researchers were acquainted with the background conditions and requirements of YCP, and in the end a limited test of the ergonomic modules of the E/S tool was arranged. The participatory approach fits quite well with the Japanese working traditions. Most of issues included in the tested modules are already tackled, but mostly in a qualitative way. The PSIM modules could provide discussions with more quantitative data.

15.1 Introduction

In the PSIM project the E/S tool (Ergonomics/Sociotechnical tool) was developed to provide software support for ergonomic and sociotechnical (STSD) analysis and design (see Chapters 8, 9, and 10). To prove the feasibility of the concept of the E/S tool and to evaluate its advantages and disadvantages the software prototype of the E/S tool was tested at selected departments of industrial PSIM partners. The background information of the test site presented here is based on observations and interviews during three PSIM researchers' four day visit to Yamatake Control Products (YCP) in Hadano, Japan, for defining the requirements of YCP for PSIM in the beginning of the project, the 'as is' analysis. The actual test of the ergonomics modules of the E/S tool at YCP was arranged as a compressed one afternoon workshop.

15.1.1 The Test Site at Yamatake Control Products

Yamatake Corporation develops and produces control products and systems in order to deliver innovative automation solutions. The corporation has about 8000 employees. Yamatake has participated in the IMS Program since its beginning in HUMACS, and other projects.

Yamatake Control Products is a part of Yamatake Corporation. The main activity of YCP is manufacturing of electronic and mechanical products and subassemblies for the automation systems of the Yamatake group. The YCP plant in Hadano employs more than 400 people.

The pilot test site for PSIM was a Printed Wiring Board (PWB) assembly line of the electronic manufacturing department. On the line components are installed on the boards with automated surface mounting machines. Three PWB assembly lines operate in three shifts. YCP manufactures various types of PWB Assemblies (PWA) in order to fulfil the requirements of various business fields of the Yamatake group companies. About 25 employees work at the test site.

Yamatake has been applying a Just in Time Concept for years. JUMPS (Just in Time Upgrade Manufacturing Process and Savemation) concept was adapted from Toyota Corporation, and is now a global philosophy for all Yamatake employees.

At YCP a special group of mostly industrial engineers enhances and co-ordinates the JUMPS concept application for continuous improvement, and each section has its JUMPS Team. One of the main ideas of JUMPS is the bottom-up approach: for the manufacturing site, participative improvement actions involve both engineers and operators.

15.1.2 The Change-Over

A PWB factory requires a relatively high level of automation (automatic insertion equipment and a lot of data to be managed (insertion programs, quality data, test data, equipment availability data, repair data, traceability data).

The lines operate automatically, but manual work is required especially for change-overs. Crates with up to 30 boards are lifted to the loading machine, and after installation, the crates with assembled boards (PWA's) are lifted from the unloading machine. Besides, cassettes with component reels (parts) are put into the machine manually.

The same lines are used for various PWA's, and several different board types are produced on the same line during a single day. Typically there are up to 10 change-overs during a shift. During the change-over a new set of cassettes is installed to the machines, the soldering mask is replaced, and the line is adjusted to match the dimensions of the next board in production sequence. The machine has space for two sets of cassettes so that the next set can be loaded during production.

Implementation of the JUMPS system involves that the intermediate stocks of boards are kept to the minimum, which leads to relatively short series of similar boards to be produced. By shortening the change-over times the processes can be changed more often without losses in actual production time.

The change-over is divided into two types of activities:

- *External change-over*: done while the line can still produce products of the previous series, e.g.:
  - fixing the component reels (Printed Wiring Devices, PWD's) to the appropriate feeding mechanisms (forming cassettes),
  - taking off cassettes,
  - putting in new cassettes,
- *Internal change-over*: done while the line has to be stopped:
  - adjusting the line for the dimensions of the next boards,
  - taking off the previous mask for soldering paste,
  - installing the soldering mask for the next boards.

In particular, setting of the PWD's requires a lot of work during the change-over, including search of PWD's, fixing PWD's to feeding mechanisms, etc. The feeding mechanisms are highly dependent on the individual specifications of machines, and thus cassettes cannot be shared by the machines.

Because of the great number of different PWA types, YCP has to handle 10 000 or more different types of PWD's in the daily operations. Monotonous operations with many similar PWD's, lead easily to a decrease of concentration, and fatigue.

The following circumstances worsen the situation:

- Surface mounting machines cannot start before completing the change-over,
- Many checking processes are required to avoid the misplacement of PWD's,
- Some PWD's often become targets of scrambling among operators.

The analysis of change-over times revealed that almost half of the change-over time was idling or loss of time or spent to search parts. Erroneous kitting was one main cause for the loss of time. Based on this analysis the 'Change-over Support System' was introduced for a better and more logical management of activities of external change-over. The time needed to carry out a change-over was decreased. As a consequence the number of change-overs per day could be increased.

15.2 The Test of the Ergonomics Modules of PSIM E/S Tool

15.2.1 Test Procedure

A workshop was arranged at the Yamatake Control Products factory to discuss the ergonomic problems of the process. The time was limited to one afternoon.

The participants were the manager from factory president's assistant staff, and the section chief, a manager, and an IT Expert of Manufacturing Engineering Section, two participants from the Yamatake corporation participating the Humacs project, and two representatives from the PSIM consortium who moderated the session.

The workshop started with an introduction to the E/S tool prototype. To use the time available effectively, the moderator had prepared preliminary proposals into different modules, based on the observations and photographs during the factory visit for the as is analysis the recent year. Due to the limited time only a few tasks could be tackled in detail.

15.2.2 Ergonomic Observations

The lines operate automatically, but there is also a lot of manual handling of parts especially during the change-over. Allocation of tasks between man and machines has been planned for the best possible efficiency, not for improving ergonomics.

As regards the *process flow*, the walking distances when searching for parts are long, causing a mark on the 'red' zone. Improvements are required. However, it cannot be solved easily, because the number of products used is so large that they can't be all stored close to the machines. Also, the often used parts are very variable.

In the *Safety and Environmental Factors* section it was observed that the light is generally sufficient for normal operations, but in some places it is difficult to see small objects, especially with regard to inspection tasks and some precision tasks. More light could improve working pace and accuracy. The workers didn't complain about it, but it was concerned as a valuable point to be discussed further.

The sharp edges of cassettes might cut into the skin of hands or fingers, but it has not caused any problems.

For *physical load*, no heavy lifts are required. However, some lifting tasks are performed in an unfavourable posture which may cause some physical load due to lifting. Cassettes weigh 2 - 5 kg, and they are handled with one hand. Often there are up to three cassettes lifted together into the machine. Full crates with PWB's or PWA's weigh about 5 kg, and they are supplied with good handles. So they are quite easily lifted to the loading machines and from the unloading machines.

During failure correction and some tasks of internal change-over the operator has to reach parts inside the machines. This leads to bent and twisted postures because of space restrictions. Most of these conditions are caused by the machine design, and cannot be improved with the current machine type.

Repetitive movements cause major problems when mounting the cassettes which involves a sequence of short movements some of which require high pinch forces.

15.2.3 Evaluation of the Modules

At Yamatake various checklists are used for JUMPS and quality systems. Checklists are already used regarding safety and physical workload. They are based on company experience. There is no software for these activities.

Mental workload module was seen as new and useful as the work is done all the time under a time pressure. The participants were very interested in methods to reduce workload, because it is experienced as a problem. Reduced concentration and working pace could be influenced. It is also related to quality control measures.

The process flow module was also seen as applicable for the processes of YCP. These kind of tools are still regarded as 'new for us'. It might be interesting to use the software integrated to production simulation for production renewal planning. There are possibilities to include sessions in quality circles meetings and kaisen meetings which now are based mostly on qualitative data.

Right now the main concern is in solving problems in production technology, but in the future there is more demand for ergonomic tools.

Because of the globalisation workers have more access to knowledge and new people have more needs for quantifying ergonomic issues and relate them to standards. The tools could be helpful. Therefore, these tools could be of use in the coming years.

15.3 Conclusion

The participatory approach fits quite well with the way of working at YCP. Yamatake (and many other Japanese companies) already tackle the issues included in the ergo modules. The additional value of the ergonomics modules is to provide more quantitative data, as in Japanese companies traditionally these issues are mostly discussed in qualitative terms.

Acknowledgements

Machiko Chikano, and Shunji Yamada of Yamatake Corporation were the facilitators of the visits to YCP. From the PSIM consortium Maguelonne Baldy, and Carla Reyneri participated in the as-is analysis, and Peter Vink in the ergotest workshop.

16. The participants of the PSIM project

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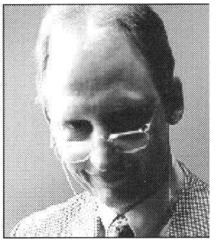
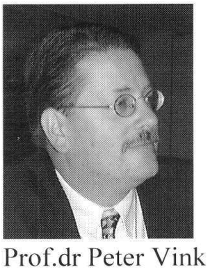


Frans van Eijnatten *TUE*

Roel van den Berg *Baan* (no picture available)

Co-ordination and secretariat



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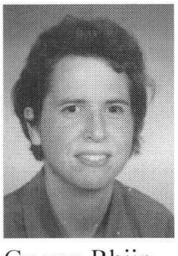

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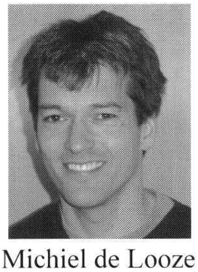

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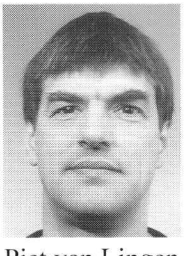

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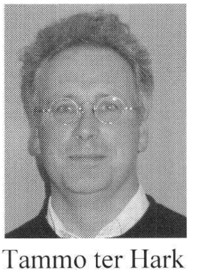

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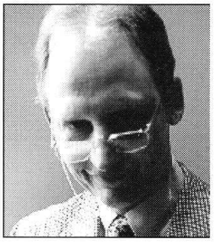
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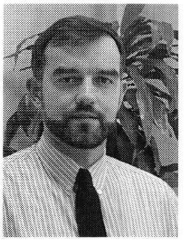
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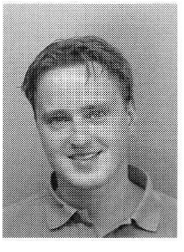
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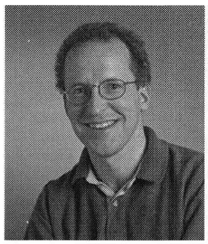
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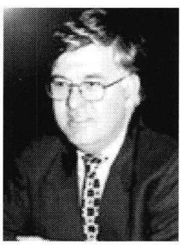
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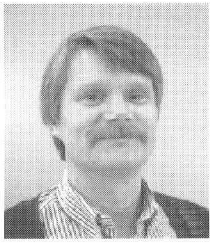
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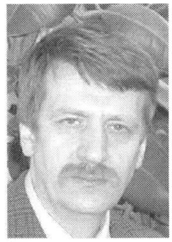
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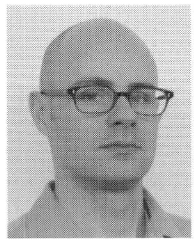
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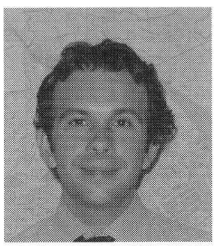
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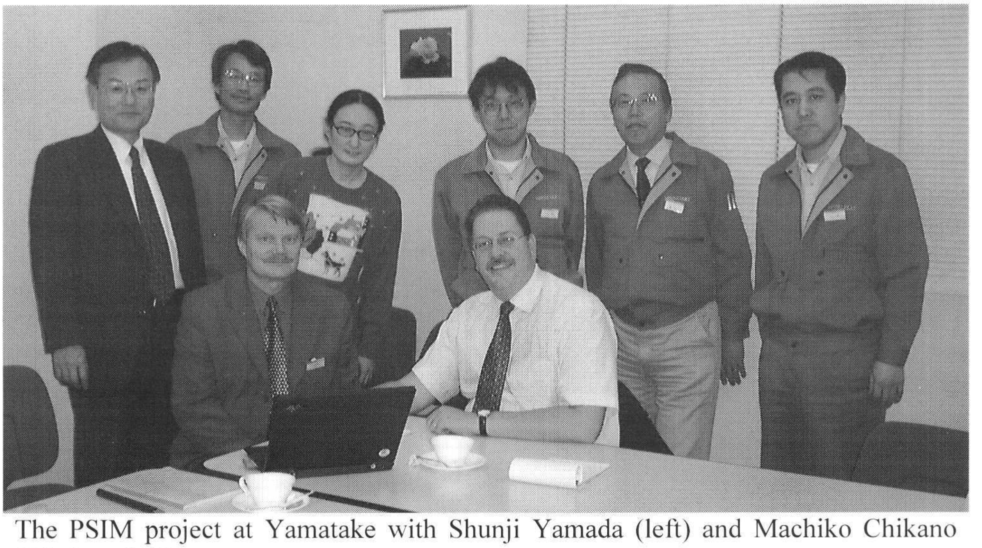

The PSIM project at Yamatake with Shunji Yamada (left) and Machiko Chikano (4th from left)

This book contains information that could support manufacturing companies in improving their production and could show researchers the positive effects of an integral approach to manufacturing renewal. Special focus was given on the human and organizational performance. The book deals with PSIM: a 'Participative Simulation environment for Intelligent Manufacturing'. PSIM is a software environment for use in assembly operations and it is developed and pilot-demonstrated in five companies.

After defining the needs of companies several parts were developed and tested. A procedure or handbook was developed. A digital language to enable better communication between several software packages (ontology) was developed. Two tools were developed. Tool 1: Socio-technical knowledge to help developing an optimal organisational structure. Tool 2: Ergonomics to help developing optimal man-machine interactions. A "navigator" was developed. This is needed to make the PSIM system usable for different participants. Also, software was developed to enable subtracting data from ERP systems (the integrator). The test results show that the approach is very complete, generates new ideas for improvement and contributes to productivity improvement, better physical and mental workload of the operators and a learning organization.