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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	co

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1 Introduction

1.1 About Holistic Roadmapping

During years two to four of the I*PROMS project a number of deliverables were compiled dealing with the taxonomy of terms, key enabling technologies, challenges facing manufacturing and research, and long and short term roadmaps for research and manufacturing. In addition, underpinning surveys on the opinion of industrial companies and also from the academic sector were conducted. These surveys would enable a much clearer understanding of the connections between the material included in the deliverables.

The last logical phase in this process that is a major concern of I*PROMS as a network of academic and research organisations is to define a long-term research agenda for future European research frameworks.

Over the years of cooperation between the four clusters that constitute to I*PROMS a natural link between the POM and IDT clusters was recognised and formed. This is due to the fact that design and organisational activities in education, research and manufacturing seem to emerge together as integral parts of one common activity. In many deliverables, issues that overlapped were difficult to separate into individual deliverables unless it was made in an artificial manner. It was recognised that a general research agenda can not separate design and organisational issues and therefore it was decided, for the sake of integrity, to compile a common deliverable and only emphasise cluster-related issues when necessary. Such an approach also leads to greater integration and cooperation between clusters, which is one of the ultimate goals of the I*PROMS project. This is another step in the integrative work of the network and permits a qualified evaluation of the harmonization between the respective plans and to what extent they represent the best solution from a holistic perspective.

Although all deliverables up to date have provided extremely useful information, many of them had attempted to deal with issues related to education, research and manufacturing separately. Therefore a need for a *holistic* roadmap was identified that includes the viewpoints of all important stakeholders into a coherent document. The holistic roadmap to define the research agenda is an attempt to fulfil this requirement. Furthermore, in times of increasing speed of innovation and reduced life cycles it is no longer sufficient to consider the different areas separately. Competitive advantages will not be achieved by focusing on a single optimization in each planning area. Instead, effective and efficient measures, i.e. holistic planning methods, will be the adequate approach to overcome this current gap. A continuous exchange of information is required to minimize the evolving planning costs and to reveal existing interactions which will increase the quality of the planning process.

Roadmaps and related documents so far have concentrated on increasing the prosperity of European industrial companies by increasing the satisfaction level of their customers. This, however, may not lead to the general satisfaction of the larger community (that falls outside the manufacturer-customer relationship), especially when thinking globally about issues like the environment and well-being of people in developing countries. This is why it was felt by the authors of this report that in many cases it was necessary to exit the narrow framework of the POM/IDT community and discuss issues in a wider perspective.

*1.2 Summary from previous I*PROMS IDT/POM reports*

The starting point of the discussions on a holistic research roadmap is naturally the conclusions of all previous reports on taxonomy, key enabling technologies, grand challenges, foresights and roadmaps of other activities relating to manufacturing. The following section details the IDT and POM cluster deliverables that were used to draft the initial list of potential topics for the study.

1.2.1 IDT Deliverables

From D6.10 Key Enabling Factors:

- Manufacturing industry is under significant change and therefore requires new and advanced technologies, systems and paradigms in order to ensure that European manufacturing industries meet the Six Grand challenges for 2020.
- The internet will become the key enabling feature in the modern manufacturing environment. It is therefore important that technologies and systems are built up around the internet such as total design technology, advanced modelling & simulation, product knowledge management, etc.
- It is clear that through the use of new and advanced (ICT based) technologies there is a major requirement to develop new and advanced methods of managing and enhancing the effectiveness of such systems. This research work has attempted to investigate technologies, systems and paradigms for the Innovative Design Technology (IDT) cluster. The KEF catalogue is a modest attempt towards classifying the IDT paradigms and further KEFs can be added however, greater inputs are required from the IDT members for this to happen.
- Industrial opinions about what is going to happen do vary, so do not reflect a single scenario, but give a variety of possibilities as far as enterprise structures are concerned. However, there is a clear expectation that uncomplicated manufacturing will shift out of Europe, design and development may partially remain European, and complicated high tech manufacturing will still stand a chance to survive in Europe. One way or another, this will lead to more complex international networks of collaborating companies. These networks will need a wide range of IDT technologies to support their collaborative and communication processes as well as advanced tools to design and manufacture high quality high tech competitive products.

D 6.11 Foresight Report:

The Foresight Report is developed based on taxonomy, State of the Art (SOTA), KEF and Industrial Surveys so it originates from academic sources as well as industrial sources. It contains a systematised view on how manufacturing companies might be operating in the future, what foreseeable conditions might occur, how these conditions might affect manufacturing. The Foresight Report uses statistical data and expert knowledge to extrapolate the current situation into the future, to forecast how future manufacturing companies will operate, based on current trends and ‘reasonable’ external conditions.

The Foresight Report is conservative by nature due to extrapolation of current trends into the future. It can not (and strictly speaking should not) take into account extreme conditions and radical ideas because they are not supported by or based on current conditions. Taking into account these extreme or unlikely conditions in the foresight report could cause substantial misunderstanding if the report is applied directly for strategic planning. This is why the foresight report should be conservative and reflect the most likely behaviour of the future manufacturing environment.

This report offers the opportunity to compare the foresights of academics and industrial people. It can be expected that both sources indicate more or less the same views, but also that there may be differences on certain aspects.
Both academics and industrial respondents share the following views:

- Product life cycles will become very short.
- The future manufacturing environment will be very efficient, flexible and adaptive.
- Products will be of high quality and accuracy, but have a low cost-price.
- International networks of cooperating companies will be common.
- Operational networks will emerge for the duration of a project.
- Environmental issues will become an important factor
- Internet and digital information exchange will be very important enabling technologies in product development and in marketing.

Some specific views from industrial respondents were:

- Social problems are expected, due to loss of low skilled industrial employment.
- Shift of manufacturing activities from currently low cost countries to currently industrial underdeveloped countries.

Some specific views from academics were:

- Holonic and agent based manufacturing environments.
- Manufacturing activities performed by humanoid robots.
- Increased functionality of CAD, CAE and simulation systems, integrating with medical scanning applications such as MRI.

D6.12 Grand Challenges:

Among the many challenges that are brought forward in this report we can distinguish some major clusters. They are indicated by both the academic sources as well as the industrial sources.
These clusters are:

- Challenges related to the product and markets
- Challenges related to technology
- Social cultural challenges
- Organisational challenges

We then summarised the major topics for the cluster:

Challenges related to the product and markets

- Mass customisation
- Very short product life cycles
- Shift from selling products to selling services
- Use opportunities offered by new technologies
- Eliminate environmental waste.
- Include the consumer in the design process.
- Secure long term product information needs.

Challenges related to technology and manufacturing

- Efficient and adaptable manufacturing
- Compete with low cost overseas manufacturers.
- Create very flexible manufacturing environment.
- Realise high quality, high precision products
- Reduce environmental damage
- Introduce holonic manufacturing systems
- Transportation becoming more expensive and less reliable.

Social cultural and societal challenges

- Prevent unemployment, find alternatives for redundant industrial labour.
- Cooperate in international networks, overcome cultural differences
- Find sufficient high level technological employees
- Educate sufficient numbers of technical students
- Create sufficient stable political conditions for R&D

Organisational challenges

- Manage virtual adaptable networks between networks
- Manage the speed of change, both in market demand as well as technology.
- Create financial conditions for R&D.
- Shift to life cycle approach instead of focus on initial costs.
- Organise and control 24 hr development processes
- Protect IPR
- Optimize supply chains

D 6.13 Research Roadmap:

The following areas are identified:

- Total Design Technology
- Advanced Modelling & Simulation Technology
- Advanced Computer Aided Manufacturing
- Automated Design of Complex Products
- Product Knowledge Management
- Networked & Virtual Enterprises for Design.

Questions:
What will be major issues for European manufacturing in the next 10-15 years?

- Water shortage
- Energy prices
- Aging population
- Climate change, temperature rise, sea level rise.

- Unemployment/education/adaptability/skill migration
- Security
- Pollution
- Traffic congestion
- Health, diseases,
- …….

What do European industries need to do to cope with these problems?

- Which are the main obstacles on the way to sustainable solutions?
- What research activities should be planned to solve them, or contribute to a solution?

1.2.2 POM Deliverables

From D7.10 Key Enabling Factors:

• Manufacturing industry is under significant change and therefore requires new and advanced technologies, systems and paradigms in order to ensure that European manufacturing industries meet the Six Grand challenges for 2020.
• The internet will become the key enabling feature in the modern manufacturing environment. It is therefore important that technologies and systems are built up around the internet such as; intelligent production systems, holonic manufacturing systems, distributed manufacturing systems etc.
• It is clear that through the use of new and advanced (IT based) technologies there is major requirement to develop new and advanced methods of managing and enhancing the effectiveness of such systems. The introduction of 'Fit' manufacture and approaches such as Advanced Production Scheduling systems etc can facilitate this enhancement process
• This research work has attempted to investigate technologies, systems and paradigms for the Production Organisation Management (POM) cluster. The KEF catalogue is a modest attempt towards classifying the POM paradigms and further KEF's can be added however, greater inputs are required from the POM members for this to happen.
Further work is needed to provide a roadmap in this area.

D 7.11 Foresight Report and **D7.12 Grand Challenges**:
• Ten Grand Manufacturing Challenges were presented as being the major issues that European Manufacturing Industry needs to address in order to remain competitive in year 2020.
• It is known that EU manufacturing industry is under significant change and therefore requires new and advanced technologies, systems and paradigms in order to ensure that European manufacturing industries meet the Grand challenges for 2020.
• The internet will become the key enabling feature in the modern manufacturing environment. It is therefore important that technologies and systems are built up around the internet such as; intelligent production systems, holonic manufacturing systems, distributed manufacturing systems etc.
• It is clear that through the use of new and advanced (IT based) technologies there is a major requirement to develop new and advanced methods of managing and enhancing the effectiveness of such systems. The introduction of 'Fit' manufacture and approaches such as Advanced Production Scheduling systems etc. can facilitate this enhancement process

• This research work has attempted to investigate technologies, systems and paradigms for the Production Organization Management (POM) cluster. The Grand Challenges document is a modest attempt towards classifying the POM challenges and the KEFs required to meet these challenges

D 7.13 Research Roadmap:
The development of this roadmap document was based on the state-of-the-art review carried out by the cluster in an earlier deliverable phase. This resulted in six key themes being identified and further described in the POM catalogue of Key Enabling Features (KEF). The key themes were: Fit Manufacturing, Virtual Enterprise, Holonic Enterprise, Individualised Manufacturing, Integration of human and technical resources and Manufacturing Knowledge Management.

The KEFs were then further developed in as series of workshops in order to develop a logical approach to bring the technological and managerial themes identified to full maturity over an anticipated timescales.

The POM cluster members considered each theme from a managerial viewpoint as well as a technological viewpoint ensuring that the POM themes interconnected with the other three more technologically oriented cluster areas. This then provided for a more integrated roadmap which concentrated on the systems which could effectively integrate the technologies into a company’s business systems.

The inclusion of results from the exploratory industrial survey enabled confirmation of the validity of the elaborated roadmap. Moreover, the importance assigned to some themes has been adapted and further issues have been included. The resulting roadmap reflects, therefore, not just the opinion of IPROMS POM members, but also of the interviewed European companies.

1.3 Comments on previous I*PROMS IDT/POM reports

- Previous reports were mainly focussed on the needs of companies and their customers. This seems to be natural because most manufacturing paradigms deal with issues of how to optimise production and how to reduce costs. Despite the general claim of companies that their ultimate goal is customer satisfaction, it is now obvious that customer satisfaction is not their overriding goal but merely the means to increase their profit. In any case, considerations rarely step outside this framework. However, satisfaction of such a limited group, even in case of global production, may not lead to the overall satisfaction and well being of people and their environment.
- The current roadmaps present an optimisation of the current state of the art and their focus is therefore from a technological perspective. Other perspectives from a sociological, environmental, cultural, ethnical and other viewpoint are not generally considered.
- Forecasts and predictions in previous reports generally assumed a reasonably stable economical environment with minimum turbulence. Recent events, however, show that despite the existence of the European Union, its members and the system at large are still vulnerable to turbulences in the global economy. Previous documents, therefore, are lacking a comprehensive answer of how the European manufacturing and research sectors would/should react to such turbulences.

- Results from the I*PROMS Industrial Delphi study were until now not included in the roadmaps. Although the I*PROMS network does include several core industrial partners and many associate members from industry, their opinion was not duly reflected in the reports that were biased toward the viewpoint of academics.
- Despite the fact that most reports were mainly influenced by the academic community, the research-oriented nature of those reports resulted in the lack of the considerations of the underpinning educational systems. Although there is an I*PROMS Study on Manufacturing Education available, its findings are not fully incorporated into a detailed discussion on the relationship between research and manufacturing with education.

1.4 Recommendations

- In an industrially oriented holistic research roadmap the findings of the I*PROMS Industrial Delphi studies, Manufacturing Education Survey, and Knowledge Transfer and Dissemination documents should be considered in detail.
- To develop a research roadmap for providing the tools that would build the capacity for the emergence of real novelties instead of marginal renewal. In order to achieve this, the group propose the method of radical roadmapping based on “what if?” scenarios.

2 Goals based on the I*PROMS Industrial Delphi study.

Since many of the respondents for the IDT & POM cluster Delphi studies were industrialists it seems reasonable that their opinions would be very valuable in any road mapping of research agendas for these clusters.

From the IDT Delphi study mass customisation is an area that the experts think will be important to European manufacturing in the future. Research into new technologies, tools and processes to deal with this expected increase should be initiated.

The experts also expect product lifecycles to reduce, and so this should also be reflected in the research agenda roadmap. Existing manufacturing paradigms such as lean, agile and six sigma should be strengthened and possibly consolidated into a new manufacturing paradigm that allows European manufacturers to compete with emerging economies, who can undercut Europe regarding manufacturing costs.
Combined functionality is expected to impact on product design in the coming years and this maybe achieved by increased usage of integrated functions, modular combinations and reconfigurability.

In order to solve the potential problems highlighted in the Delphi study of shortage of human capacity and expertise, research on ubiquitous design and manufacturing could be important. Research into aspects of time differences with regard to world-wide multi-cultural networks would therefore seem to be an important area for inclusion in the IDT research roadmap.

Environmental issues such as fuel shortages & costs and recycling are expected to be major issues in the 21st century and beyond, so it is vital that the research agenda addresses these topics in the coming years. Research into new and alternative fuel sources will be required to reduce the impacts of both cost and supply of traditional fuel types. Research aimed at developing more advanced design tools and methods for recycling will be required.

Research into areas relating to retaining product information and traceability were identified as important to European manufacturing by the IDT cluster Delphi study.
Research should be directed at further developing design methodologies and tools for designing rapid manufactured parts. Research should also be directed to developing new technologies for the materials, along with new Design-for-Manufacture tools to cover the manufacturing processes that use these materials. Flexible manufacturing and the use of virtual factories and manufacturing simulation models will both be very important, so targeted research in these areas should be incorporated into the IDT research roadmap.

2.1 Conclusion from the IDT Industrial Delphi study

2.1.1 Mass Customisation in the Manufacturing Sector

The experts who participated in the IDT Delphi study indicated that mass customisation in the manufacturing sector is becoming more important and that by 2020 they expect that it will be twice as common as present levels.

Research to develop ideas on how this increase in mass customisation can be achieved and which technologies will affect this increase should be addressed.

Development of design tools and structures that would allow larger input into the design of products from customers, both expert and non-expert may be developed to facilitate the increases in mass customisation.

The impacts of mass customisation on quality and safety should be considered. These will have to be maintained even though the cost of such products is expected to fall.

The opinion from the Delphi study tends to suggest that customers will expect the cost of mass customised products to be reduced by up to 50%, so the tools and structures developed to aid with mass customisation should also be cost effective. The opportunities for designers to deal directly with their customers will increase in the coming years.

Issues such as how to capture the design that the customer wants will be important issues in the coming years. The experts expect the social and economic impacts of increased mass customisation to be quite high.

2.1.2 Product Life Cycles

The experts predict that time to market will be reduced by 50%. Consideration to how this shortening can be achieved can direct future research activities. Issues such as applying lean engineering could help with this. The new and emerging technologies that can facilitate this reduction in product life cycles should be identified and developed. Safety and quality issues should also be considered when trying to reduce product life cycles. The environmental impacts of such initiatives are also important and need to be considered.

Consideration must be given to ways that European manufacturing industries can take advantage of the shortening time to market, whether it's a threat or an opportunity will be important, and this may vary from product to product or sector to sector. Most of the experts think that this will be an opportunity which will have high social and economic impacts.

More outsourcing may be affected by cultural barriers. This may also lead to a loss of skill levels in those regions where outsourcing becomes more common. European industry will need to be able to enhance the performance of their suppliers The impacts of shorter product lifecycles on quality and safety should be considered. The experts expect the social and economic impacts of shorter product lifecycles to be quite high.

2.1.3 Opportunities offered by new technology

The experts tend to agree that products will continue to be developed with more combined functionality in the coming years. The impact these developments will have on multidisciplinary design tools also needs to be considered. The expected combined functionality may be achieved by using integrated functions, modular combinations and reconfigurability. All of these are expected to contribute. Innovations in this area are expected to be funded by individuals, EU and National funding bodies. The experts expect the social and economic impacts of opportunities offered by new technology to be quite high.

2.1.4 Co-operation

The experts predicted that cultural knowledge and human capacity would be important factors in co-operation activities. It is important to note that differences apply across disciplines and national tastes and that the way decision making is done differs across cultures. To solve the problem of shortage of human capacity and expertise, research on ubiquitous design and manufacturing is needed. Research can be carried out into what are the relevant aspects of time differences with regard to world-wide multi-cultural networks. The experts identified this as the problem area in such networks. Identification of the benefits and mechanism of standardisation, and its effects on multi cultural manufacture will also need to be addressed. Research into taxonomies of IDT may help overcome language interpretation problems. A challenge for designers is to maintain the particular brand identities. A major research target should be to find ways protect long term brand identities. The experts believe that the social and economic impacts of co-operation could be quite high.

2.1.5 Environmental issues

The experts' opinions on fuel types that will be used in 2020, show that fossil fuel usage is expected to fall to as little as 50%. Increases in other energy types, in particular nuclear are envisaged. Research to try to identify any bio-sources of fuel that do not conflict with food resources will be required. Design challenges to develop machinery that uses and produces bio fuels would help to address this. The production of cheaper solar cells could be important. Research needs to be conducted to quantify amounts of solar energy needed to support current and future energy needs.

A method for capturing tidal and geothermal energy is an area where research capacity could be directed. An area of potential energy production research could look at methods to make wind power more efficient.

The experts think that recycling will be an important issue for European manufacturing by 2020. They predict that between 40-60% of materials will be recycled within Europe by this time. Research aimed at developing more advanced design tools and methods for recycling, such as disassembly will be required to meet these expectations. Other related areas include Design-for-Recycle tools and methodologies, designing recyclable materials and products. Consideration should be given to predicting the cost and environmental impact of recycling. Methods to tackle the problems earlier on in the process would be advisable.

The experts believe that the social and economic impacts environmental issues will be high.

2.1.6 Product information needs

Regarding product information for manufacturing companies in Europe (service, repair, recycling, liability and legal responsibilities) the experts think that part traceability, changing standards, IPR security, retiring workforce, compatibility of IT systems and IPR and copyrights expiring will be important for European manufacturing industries.

The social and economic impacts of these factors varies with part traceability, changing standards, IPR security, compatibility of IT systems and IPR and copyrights expiring are all expected to be relatively moderate. The social and economic impacts of retiring workforces are expected to be higher however.

Research areas identified by the IDT cluster relating to these topics are development of new tools for integrating product traceability, new methods to preserve expert knowledge from the retiring workforce and tools for standard integration Quantification of the cost and the risk of the loss of knowledge would be useful.

2.1.7 Adaptable Manufacturing

The experts predict that production in terms of sales value will be accounted for by 10-15% of individual, one offs, 20-30% of small series and 50-60% of mass manufacturing by 2020.

After both rounds it appears that the experts think that the current rapid prototyping technologies will become part of mainstream manufacturing processes in Europe, USA and Asia by 2015-2020. The perceived social impact varies from no impact to large impact across the experts. The economic impacts of this will are expected to be relatively high.

Research could be directed at further developing design methodologies and tools for designing rapid manufactured parts.

The experts expect that metals, composites, plastics, elastomers will be important in relation to rapid manufacturing in Europe by 2020. Less importance was placed on ceramics and organic material.

Research could be directed to developing new technologies for the materials, along with new Design-for-Manufacture tools to cover the manufacturing processes that use these materials.

The experts who took part in the Delphi study indicate that the use of virtual factories and the use of manufacturing simulation models will both be very important with respect to flexible manufacturing. The expected social and economic impacts of these are large.

2.2 Conclusion from the POM Industrial Delphi Study.

2.2.1 Minimising Environmental Damage

The experts who participated in the POM Delphi study indicated that the reduction of production waste and product environmental impacts is a critical issue for manufacturing industries in Europe over the coming years. They predict that the improvement in all manufacturing processes as regards energy consumption could be up to 50%. Similarly with regard to pollution levels they predict that the improvements could be up to 50%. They also indicated that they expect the social and economic impacts of these issues to be large. Regarding the development of eco-friendly manufacturing standards in Europe, approximately two thirds of the experts believe these will be developed in the next 10 years, and most of the remaining third set the horizon at 20 years. With the added social and economic impacts of this been rated as large it seems that environmental issues will be very important to future POM research directions.

The POM cluster partners believe that the goal of manufacturing enterprises will be to develop new competitive products and processes that are cost effective, do not harm the environment, use recycled materials, and do not produce large amounts of waste. To facilitate this, use of environmental standards and eco-labels is predicted for the near future. This will require the creation of new knowledge and information systems. Using the global database on environmentally harmful materials and best practices on recyclability and reuse will be key elements in meeting this challenge.

2.2.2 Innovative Products, Technologies, Processes & Services

Advances in information technology, computer tools, automation, and advanced work practices have helped to improve manufacturing industries in Europe over the last few decades. High market transparency and an increasing dynamic in the business environment have continually intensified the competitive conditions of manufacturing companies in recent years. Developing a culture aiming for continuous innovation and growth through new product and process development is seen as critical for the development of new and innovative concepts in EU industry. Constant product and process innovations are the only way to compensate the loss of market share especially in high-wage countries in the mass production sector. The experts involved in the POM Delphi study believe that up to 40% of new product development processes will be facilitated by use of virtual reality.

In addition they indicated that they believe economical & political systems will be conducive towards these innovative products, technologies, processes & services. Related to this, they expect the social and economic impacts to be large.

Regarding the direction that these innovations could come from, they predicted that 10% of new products could be influenced by science fiction films and books.

2.2.3 Collaborative Design, Research and Manufacturing Environments

Developing strong industrial & academic links is seen as vital for European manufacturing companies in creating new products, services and systems. In addition they must also concede that to achieve critical mass of skills, technologies and knowledge they must collaborate with other companies who they have traditionally viewed as competitors. But if sustainability is to be achieved, they must re-asses their relationships with these competitors and move toward the collaborative environment.
The experts who participated in the POM Delphi study indicate that implementation of chaos and complexity management within manufacturing organisations will be very important for European industry by 2020. Traditionally, system's complexity is seen as a negative feature and management's goal is to eliminate or reduce it. The theory shows that the complexity is a condition for emergence of a real novelty. From that point of view, management moving towards increasing & nurturing complexity in order to increase the potential for real novelty is an indispensable requirement of advanced, competitive and sustainable organisations. Growth of the environment dynamics & complexity is a fact which consideration is a must for management. The same is also true for an organisation's internal issues. Conversely, it is unrealistic to expect that there will be simple solutions for these complex environments, so the complex environment requires complex solutions.

The experts indicated that 80% of products will have direct involvement between product developers and customers in Europe by 2020. The social and economic impacts of this are also predicted to be large.

In addition the experts predict that interoperability of product data information systems will be commonly used both within and outside companies by 2020. The level of agreement is less than that for within companies however. Again the social and economic impacts of this are thought to be large.

2.2.4 Knowledge Management & Improved Decision Making Systems

Knowledge and innovation are of growing importance in the industrialised nations. Product life cycles will require better identification, structuring, storage and reuse of knowledge. Concurrent design and manufacturing will require the real-time transfer of information between designers and manufacturers, and an efficient use of this information with the support of formalised knowledge bases. Advances in education may offer the best opportunities as trained and educated people will be able to separate useful information from useless information.

The experts who participated in the POM Delphi study have differing opinions as to their estimates of the percentage of all workers that will be making use of business intelligence in European manufacturing industries by 2020. Most expect the figure to be anything up to 50%, with fewer of them predicting even higher than this.

Most of the experts agree however, that the knowledge society will create new manufacturing paradigms. They also predict that the social and economic impacts of this will large. Regarding organisations utilising knowledge based decision making tools, the experts expect that 70% could be doing so by 2020 in Europe. The advantage of the rule-based model is that it provides a documented, logical structure to the decision-making process that is both intuitive and experiential. Such models can process quantitative data but are most useful when coping with qualitative information to reach decisions. Rule-based models build on what is

These types of models have become known as knowledge-based systems or expert systems. Most of the experts agree that knowledge management will increase the efficiency of the decision making process at both company and individual level. The social and economic impacts are expected to be large.

2.2.5 Change Management & Leadership

Change management and leadership are expected to be key for European manufacturing organisations in the next 20 years. In order to withstand changes in the market and technological developments at the same time as changing customer needs, it is important to retain workforce knowledge and skill in addition to their personnel capabilities. Furthermore, changeable production systems that can be integrated into an information intensive manufacturing system are inevitable for creating manufacturing leadership. Change management is connected to the life-cycle including all resources of an enterprise. In an holistic sense, it is not enough to consider only the product life cycle, but as well the life cycle of technologies, factories and human resources. It is not sufficient to be aware of tendencies within the individual planning fields. Instead, knowledge of the interdependencies or interfaces between each area is important. The relationships and interactions have to be systematically explored and roadmaps are an adequate way to lead the different sections into the same directions as well to actively anticipate changes in the future. It will be necessary to develop systematic and manageable methods in order to avoid responsibility conflicts between different planning departments and reduce the costs of co-ordination and synchronization. A systematic coordination is required to transfer the strategic goals into the operative planning phase. There must be a continuous exchange of information between the respective areas because this is the only way to minimize the cost of planning work, take interactions into account, and improve the quality of planning.

Clear manufacturing leadership could result in increasing employee satisfaction and manufacturing effectiveness. New technological and paradigm developments should be managed correctly within the industrial environment. Designing, developing and implementing new paradigms will be an important challenge so that EU industry can stay ahead of highly efficient competitors.

The experts who contributed to the POM Delphi study were asked for their opinions on a number of management techniques and tools. Most had no strong opinion on whether individualised manufacturing would help to meet the challenges of 2020. However they did agree that ERP, lean engineering, agile engineering, product life management (PLM) would help to meet the challenges.
They also agreed that change management & leadership will have a strong impact on strategic thinking. They indicated that the social impact of this would be moderately high, and that the with economic impact would be larger.

2.2.6 Enterprise integration and Time to Market Reduction

The POM Delphi study indicated that achieving economic sustainability was the major priority of most of the experts involved. One of the key strategies towards achieving sustainability is the need for companies to significantly reduce design to manufacture lead times through developing a concurrent approach to their manufacturing operations. Concurrency can be defined as planning, developing, and implementing carried out at the same time in parallel, rather than sequentially. For maximum efficiency conceptualisation, design, and production of products and services should be as concurrent as possible to reduce time-to-market, encourage innovation, while still been able to guarantee quality.

Most of the experts predicted that 60% business intelligence will be required for competitive manufacturing. They also predict that up to 60% of time to market reduction will be as a result of implementing concurrent engineering methods.

Interoperability means eliminating, reducing or hiding, the equipment and software heterogeneity as a factor in organisation, system and operation integration. This is an important issue as rapid development of new equipment and technologies implies needs for new (HW/SW) interoperability solutions – for design, implementation and management of interoperability solutions. The experts rate the interoperability for enterprise modelling as important. Interoperability means eliminating, reducing or hiding, the equipment and software heterogeneity as a factor in system integration and operation too. This is an important issue as rapid development of new equipment and technologies implies needs for new (HW/SW) interoperability solutions – for design, implementation and management of interoperability solutions. Interoperability solutions are, in principle, different in nature and importance for intra- and inter-enterprise domains, as well as in the present and in the future. The experts rate the interoperability for enterprise modelling as less important than intra-enterprise interoperability.

2.2.7 Global Logistics & Long Supply Chain Management Systems

Efficient and responsive supply chains are vital for European manufacturing industry to remain competitive over the next 20 years and beyond. As the levels of outsourcing increase the task of managing the complete supply chain will become more important. Europe should aim to develop localised highly technological competence and methods so that the knowledge and information systems of distributed companies can be efficiently linked. This will be especially challenging for SME's which already have difficulties for developing the competences allowing them to efficiently use the information transmitted by their large customers. These difficulties are expected to increase in the near future with the widespread use of the intelligent product technologies, such as RFID.

The experts who participated in the POM Delphi study were asked to state if they agreed that certain factors would have a strong impact on global logistics and optimised supply change management. Most agreed that new transport methods, energy prices, customer/supplier relationships and ambient intelligence will all have a strong impact.

They also indicated that the social impact of these factors would be high, with an even higher economic impact. Most of the experts also agreed that supply chains will get shorter in the coming years. Again the social and economic impacts of this trend are expected to be large

3 Results from the I*PROMS Study of Manufacturing Education.

It is important to know the requirements of the industry in terms of the qualification and knowledge of its employees as compared to the manufacturing related education being taught by the institutes to satisfy the relevant knowledge/skills requirements.

I*PROMS researchers identified various knowledge/skills in the area of manufacturing, from the previous industry based reports, that are currently taught within various I*PROMS partner institutes. These knowledge/skills are conveniently split into the following broad subject groups:

Conventional Manufacturing Processes – conventional machining processes, forming processes and casting and moulding processes.

Advanced Manufacturing Processes/Techniques – non-traditional machining processes, rapid prototyping and reverse engineering and CAM/CNC technology.

Precision Engineering – micro and nano technology and quality assurance and inspection.

Design – drawing interpretation, design for manufacture, finite element modelling, rapid prototyping and reverse engineering and life cycle engineering.

Management – lean manufacturing, production organisation and control, materials resource management, cost control, global manufacturing and project management.

General Knowledge/Skills – general programming skills, communication skills, IT skills and team working.

Industrial organisations level of satisfaction on the knowledge/skills of their recently recruited graduate engineers were recorded. In order to quantify the responses, the scores of Dissatisfied = 0, Moderately Satisfied = 2, and Highly Satisfied = 5 was used.

The average scores for these six knowledge/skill groups are shown in figure 1:

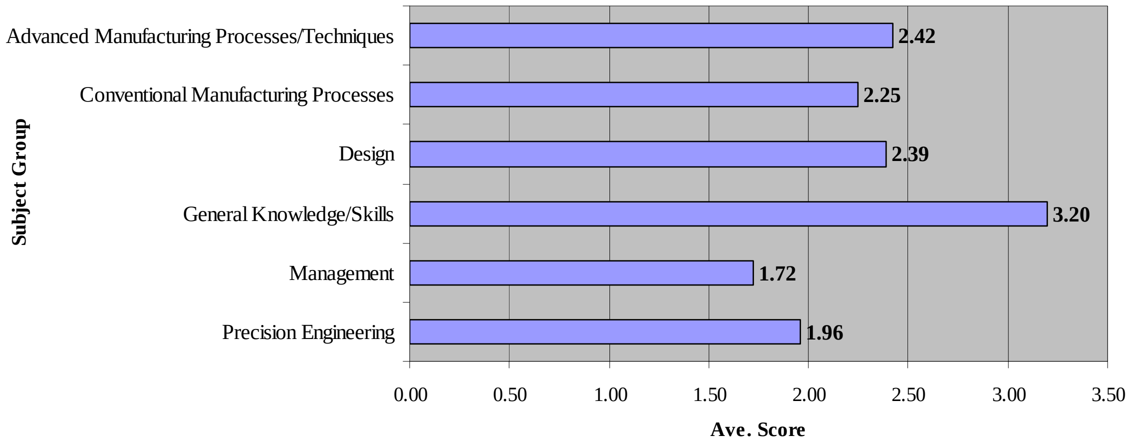

Figure 1: Subject Groups Knowledge/Skills Scores

For the IDT and POM industrial holistic roadmap, it is important to consider the maximum and minimum amount of academic provision of the two subject groups Design and Management within Europe. The provision response is recorded as none, moderate or extensive provision. No provision is obviously where the student has no exposure to the subject whatsoever. Moderate provision is where there is some, but not significant, exposure to the subject such as when subjects relevant to several relevant knowledge/skills are covered in a single module. In order to quantify academic provision in a similar way to that which was done for industry's satisfaction with knowledge/skills, the scoring of 0 = No provision, 2 = Moderate provision and 5 = Extensive provision was used and the following results were produced.

IDT related Knowledge/Skill	**Max. Provision Score**	**Min. Provision Score**	**Satisfaction Score**
Rapid Prototyping and Reverse Engineering	2.27	1.13	2.50
Micro and Nano Technology	1.47	0.60	2.00
Quality Assurance and Inspection	3.33	1.40	1.92
Drawing Interpretation	2.67	2.33	2.58
Design for Manufacture	3.47	2.73	2.46
Finite Element Modelling	1.40	0.47	2.50
Life Cycle Engineering	1.43	1.00	1.91
Overall Average	**2.29**	**1.38**	**2.27**

POM related Knowledge/Skill	**Max. Provision Score**	**Min. Provision Score**	**Satisfaction Score**
Quality Assurance and Inspection	2.33	2.00	1.92
Lean Manufacturing	0.80	0.53	1.40
Production Organisation and Control	4.47	4.07	1.69
Materials Resource Management	1.33	0.60	1.42
Cost Control	1.33	1.33	1.36
Global Manufacturing	1.33	1.13	1.67
Life Cycle Engineering	1.93	1.40	1.91
Project Management	1.93	1.93	2.79
Overall Average	**1.93**	**1.62**	**1.77**

In general the IDT and POM related topics indicate that in most cases the industrialists' belief that these topics are not adequately covered in the engineering degrees is supported by the analysis of the course modules. The above data could be interpreted in the following manner;
Max. Provision Score and Min. Provision Score > Satisfaction Score:
Design - Design for Manufacture;
Management - Quality Assurance and Inspection; Production Organisation and Control;
This signifies that these particular subjects are very will covered and taught in the partner institutes, and more time is devoted to these topics in more specialised degrees.
Max. Provision Score > Satisfaction Score > Min. Provision Score:
Design - Quality Assurance and Inspection; Drawing Interpretation;
Management - Life Cycle Engineering;
This signifies that the particular subject is taught as an optional subject in the partner institutes, and that the topics are not well covered in some academic partner institutions, or this may be in part due to these topics been covered in more general modules that are not exclusively devoted to these areas.
Satisfaction Score > Max. Provision Score and Min. Provision Score:
Design - Micro and Nano Technology; Finite Element Modelling; Life Cycle Engineering;
Management - Lean Manufacturing; Materials Resource Management; Cost Control; Global Manufacturing; Project Management;
This signifies that the particular subject is not covered and taught as in the depth, as required by the industry.

Industrial organisations surveyed suggested knowledge/skills related to manufacturing design and management that they felt would be required in the future if they were to remain competitive are listed below;

- Advanced software techniques, including ICT and CAD/CAM tools
- Integration of design and manufacture/design for manufacture
- Rapid prototyping
- New manufacturing processes/techniques
- Process planning
- Virtual manufacturing
- Reverse engineering
- Life cycle engineering
- Production control, organisation and planning
- Cost management
- Environmentally friendly processes

4 Frameworks for building Radical Roadmaps

Introduction to Frameworks
A holistic research Roadmap is a multidimensional perspective with intention to be complete, i.e. as much as possible complete, in regard of totality of the Roadmap's

"stakeholders" needs and requirements. The multidimensional perspective implies the perspectives from heterogeneous theories, corresponding to the heterogeneity of needs and requirements of the Roadmap heterogeneous "stakeholders". Therefore, in order to assure the highest degrees of completeness of the perspectives as well as to relate them to each other, speaking in engineering terms, instead of an "ad hoc" approach and more or less intuitive approach, a framework for the holistic research Roadmap development would be useful. The function of such a framework is to improve the effectiveness and efficiency in development and implementation of the holistic Roadmap, including validation of the Roadmap structure and content developed.
Such a framework, using theoretical terms, could be called a meta-theory for holistic Roadmap development. "*A meta-theoretical perspective, …(is) a critical framework for analysis, and creating a structure that enables elements of different theories and concepts to be located relative to each other.*"(Love, 2000, p. 304)
As a contribution to holistic research Roadmap development we propose here three frameworks:

1. Abstractions hierarchy framework
2. Semiotics framework
3. Complexity framework

(Note: This Chapter is based on (Putnik et al.; 2005), (Eijnatten& Putnik, 2006) and (Eijnatten, Putnik and Sluga; 2007)

4.1 Abstractions Hierarchy Framework

The proposal for the abstractions hierarchy framework for the holistic research Roadmap development based on the abstractions hierarchy follows the work by Love (2000). "It offers a means of classification that is hierarchical and relatively independent of the domain-based meanings associated with each theoretical element. This method provides a straightforward means of clarifying and externalizing many of the hidden dependencies between abstractions in" the IDT and POM domains. The abstractions classification is "focused not on the *content* of the abstractions or theories. This is a taxonomy of abstractions and theories in terms of their theoretical *behaviour*" (Love, 2000, p. 305).

The hierarchical levels of IDT and POM abstractions, in which IDT and POM might be researched, are presented below.

For the IDT domain, the abstraction levels are directly compiled from (Love, 2000, pp. 305-306), as the source is directly addressing the design domain.
For the POM domain, the abstraction levels follows and paraphrases (Love, 2000, pp. 305-306).

<u>Abstractions Hierarchy Framework for the IDT domain</u>

1) *Direct perception of realities*—This is the level at which we 'sit on chairs', 'watch sunsets', 'hear the sound of a bird'...—*'The woodworker feels the movement of the hammer as the nail is driven.'*
2) *Description of Objects*—The level that encompasses simple descriptions of objects, processes and systems—*'a vacuum cleaner', 'a car body', 'a groyne', 'a typeface', 'a database'… 'The woodworker uses a "claw hammer" rather than a "chisel".'*
3) *Behaviour of Elements*—The level at which the behaviour of elements which may be incorporated into objects, processes and systems is described. *For example, 'a camshaft rotates at 600 revs/sec', 'headline type needs to be set closer than body*

text', 'the lower windows need to offset the visual weight of the portico', 'the melody returns to the tonic'. 'The hammer is made up of two parts; a head and a handle… The correct angle between the handle and the face of the hammer head is necessary for nails to be hammered in straight.'

4) *Mechanisms of Choice*—The level of descriptions about the way that choices are made between different objects, processes, or systems, and how solutions are evaluated. *For example, 'Why does a woodworker choose a claw hammer rather than a sledge hammer for hammering a small nail?'*
5) *Design Methods*—The level in which theories about and proposals for design methods and techniques are described—*The theories about designing wood artefacts. 'How does one design a chair?'*
6) *Design Process Structure*—The level that includes the theories about the underlying structure of design process, and the influences of domain, culture, artefact type and other similar attributes and circumstances. *For example, 'What are the processes underlying the design of Polynesian catamarans?'*
7) *Theories about the Internal Processes of Designers and Collaboration*— This level includes the descriptions of theories about the reasoning and cognition of individual designers, of negotiated design in collaborative design teams, and of cultural design effects on designers' output. *For example, 'How did Mackintosh design furniture?' 'What communication is necessary between the different designers of timber framed housing?'*
8) *General Design Theories*—This is the level that is concerned with the details of those general theories which seek to describe the whole activity of designing and its relationship to the objects involved. *For example, 'The activity of designing a boat, or a turbine, or a comic strip can be described as follows....'*
9) *Epistemology of Design Theory and the Theories of Objects*—This is the level that contains those analyses and discussions about the critical study of the nature, grounds, limits and criteria or validity of design knowledge—*'What is a theory of design?', 'What does it include and exclude?', 'On what assumptions is this theory based?'*
10) *Ontology of Design*—The philosophical study of the ontological basis for design theory and the activity of designing. It is at this level where human values, and the values and fundamental assumptions of researchers, are included in critiques of theory. *For example, 'Which human values and assumptions effect the design of new legislation for narcotics?', 'Are the methods of evaluation used to choose between different design alternatives consistent with the ethical proscriptions of the relevant professional bodies?', 'What is reality?', 'What is existence?'.*

<u>Abstractions Hierarchy Framework for the POM domain</u>

1) *Direct perception of POM realities*— At this level, we observe the daily work-life interactions within the POM domain
2) *Description of POM Objects*— At this level, we describe POM objects, processes, and systems
3) *Behaviour of POM Elements*— At this level, the behavior of POM elements that may be incorporated in objects, systems, and processes is described.
4) *POM Mechanisms of Choice*— At this level, we describe the way choices are made between different POM objects, processes, or systems, and how solutions are evaluated
5) *POM Methods*— At this level, the theories about the underlying structure of the POM process are described.

6) *POM Process Structure*— At this level, the theories of the underlying POM processes are described.
7) *Theories about the Internal Processes of POM users and their collaboration* — At this level, theories about the reasoning and cognitions of individuals and collectives using POM are described
8) *General POM Theories*— At this level, the general theories about the whole framework of POM are described.
9) *Epistemology of POM Theory and the Theories of Objects of POM* — This level contains the critical study of the nature, grounds, limits, and criteria or validity of POM knowledge.
10) *Ontology of POM* — This level contains the philosophical study of the ontological basis for POM, such as assumptions, ethics, and human and social values.

4.2 Semiotic Framework

The proposal for the semiotics based framework for the holistic research Roadmap development follows the emerging areas of organizational semiotics and research of the fundamentals of information systems based on the semiotic framework (organizational semiotics, semiotic framework) that have emerged in response to the failure of the traditional "techno centric" approach to today's information systems (IS) and organizations (ORG) requirements as well as to the "software development crisis." The software development crisis is manifested by the approximately 50% failure rate of the software projects (e.g., see Liu, 2000, for the "shameful numbers"). According to R. Stamper ["A Dissenting Position" in *FRISCO Report* (Falkenberg et al., 1998)], the traditional approach fails "not for technical reasons - most delivered software performs efficiently to specification – but for organizational reasons - they do not relate correctly to the world of business reality. The sad facts that, in general technical people do not understand business problems and business-oriented people do not understand the need for detailed, formal precision contribute to the problem." In the *FRISCO Report* (Falkenberg et al., 1998), it is identified that "there are at least three major sources of problems: (a) the large variety of interest groups, (b) conflicting philosophical positions, and (c) the lack of understanding communication." Also, it was realized that "the social, cultural and organizational aspects play more decisive roles then technology itself" (Liu, 2000, p. 3). "Organization is achieved not by doing things but by talking and writing about them," said Stamper.

Thus, a better understanding of IS should be based on a broader sociotechnical view and should "encompasses human beings, organizations, business processes, standards and tools" (Hesse & Verrijn-Stuart, 2000, p. 1; see also Table 2). According to Moor and Weigand, information systems should be approached "much more as the communication systems than computation systems" (Moor & Weigand, 2002; see also Table 1). To deal with the communication systems, the "move away from the traditional information flow paradigm, in which positivistic modeling of symbol manipulating functions aimed at producing automated solutions is central, …, (towards) an information field paradigm is needed (Stamper, 2000). … The information systems built on the information field paradigm do not produce sterile data, but aim to generate and communicate information that can lead to true knowledge that helps people to perceive, understand, value, and act in the world" (Moor & Weigand, 2002; see also Table 2).

According to Stamper (1996; cited in the *FRISCO Report*, Falkenberg et al., 1998, p. 13), semiotics offers the explanation of the new approach on six semiotic levels (called the “semiotic ladder”) (Figure 1).

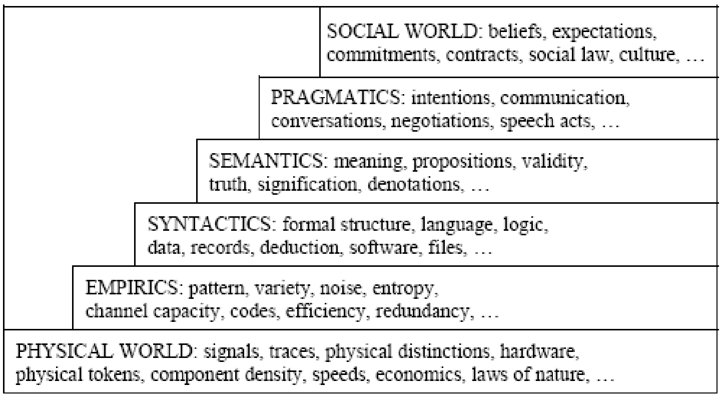

Figure 1. The “semiotic ladder” (after (Stamper, 1996))

Table 1. From information to communication systems (Moor & Weigand, 2002)

	Information Systems	**Communication Systems**
Focus:	Information	Communication
Supports:	Transaction processes	Communication processes
Design objects:	Clear specifications	“Fuzzy” process definitions
Development process:	Single project	Continuous process
Developers	Elite development team	Many stakeholders

Table 2. From information flow to information field (Moor & Weigand, 2002)

	Information Flow	**IS Information Field**
Change:	Static	Dynamic
Responsibility:	Anonymous	Individual responsibilities
Design process:	Representation	Interpretation
Objective:	Control	Perceive, understand, value, act
Control logic:	Rules	Norms

Concerning IDT and POM domains, the semiotics framework implies consideration not only the technical issues, i.e. technical solutions as such, but HOW the technical solutions ARE USED and ACCEPTED (by humans, by society. Consequently, the use and acceptance depends of interpretations meaning that the same technical solutions might be accepted or rejected in different social groups. One of the main processes is therefore the process of “negotiating” and “co-creation” of solutions which will be in full coherence with all stakeholders. In other words, it means that the “initial” solution is not so important as it will be adapted through negotiation and co-creation processes.

Consequently for the future solutions, what matters are the levels of pragmatics and ‘social’.

Therefore, the holistic research Roadmap for IDT and POM domains should necessarily incorporate the pragmatics and social perspectives too.

4.3 Complexity Framework

The third framework proposed for the holistic research Roadmap development is the Complexity framework. This framework is of the special importance as the present environment of the production organizations is becoming more and more dynamic reaching the turbulence.

Therefore, **the holistic research Roadmap should address the issue of design and management and innovativeness of production systems in turbulent environments.**

The issues of design and management and innovativeness of production systems in turbulent environments come from the Chaos and complexity management in organizations discipline (or science).
Chaos and complexity management in organizations is an emerging management discipline, and an emerging management paradigm, aiming to provide the organizations with capabilities such as capability for real novelty, “flow” organizational structures (instead of fixed ones), coherence, true learning, as well as for achieving the “traditional” objectives as agility, permanent and “on-line” alignment with the market, i.e. environment, etc., in order to deal with the 21st century environment and intrinsic conditions characterized by **growing complexity** leading to the “traditional” organizations’ inconsistencies, contradictory demands, dilemmas in decision making, malfunctioning of systems, and similar (Eijnatten, 2004a).

One of the approaches to chaos and complexity management in organizations is based on so-called **Chaordic System Thinking (CST)** – as “a complexity-focused framework for seeing and interpreting organizational patterns that are often anchored in the meta-praxis of chaos” (van Eijnatten, 2004).
While by the actual, “traditional”, management paradigm the complexity is seen as a problem that have to be reduced, controlled and, if possible, eliminated, **as negative phenomena**, **by the new paradigm the complexity is seen as a condition for creating the potential and emergence of the real novelty**.
The concept of the ‘real novelty’ might be characterized as the creation of an artifact – real or virtual – that *neither duplicates nor copies any existing device*. This is presented in Figure 2.

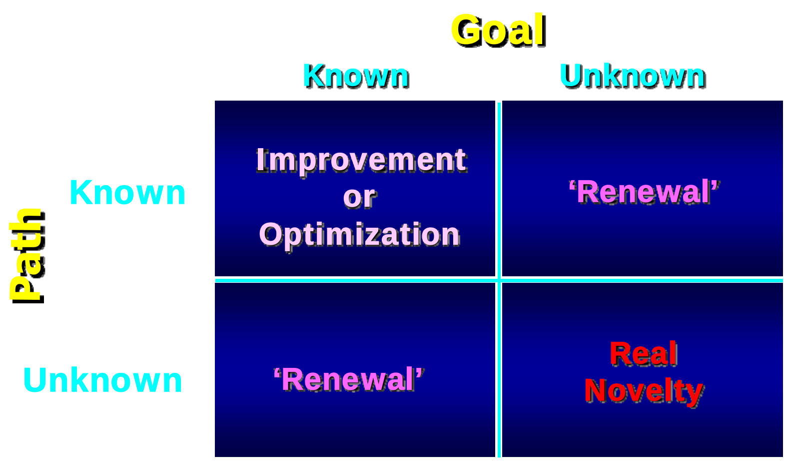

Figure 2. ‘Real novelty’ characterization

To address turbulent environments and a real novelty creation, as a critical success factor in dealing with the turbulent environment, the IDT and POM systems could use the CST perspective. CST uses as its pivotal model the Sigmoid Curve of

Discontinuous Growth, which is a *qualitative* reading of the logistic function in Nonlinear Dynamics Theory [6]. Two basic dimensions in this model are time and complexity / coherence, not productivity, see Figure 3.

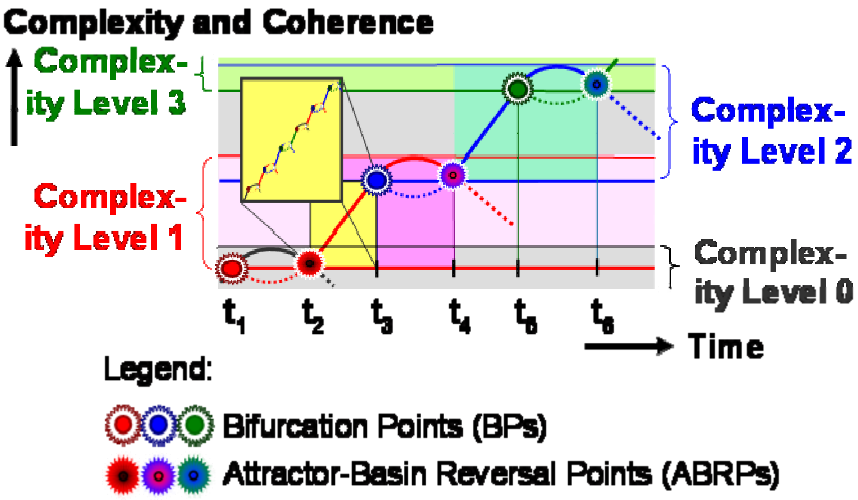

Figure 3. Discontinuous Growth of organizations

Central ideas behind the model are that:

1) Systems do have life cycles;
2) They are functioning at particular complexity levels which both offer and restrict further opportunities for growth; and
3) They go through successive periods of relative stability and instability.

The central issue is how the transition is taking place from the lower plane to the higher level of complexity and coherence, see Figure 4.
This unstable phase following bifurcation is characterized by chaotic changes in both thinking and doing of MS professionals.
At the lower complexity- and- coherence level their behavior is typified by Old Thinking / Old Doing.
The higher- plane behavior can be identified by New Thinking / New Doing.
The two intermediate stages are best described by schizophrenic combinations of Old Thinking / New Doing and New Thinking / Old Doing as professionals are experiencing major dilemmas and contradictions between which they constantly alternate.

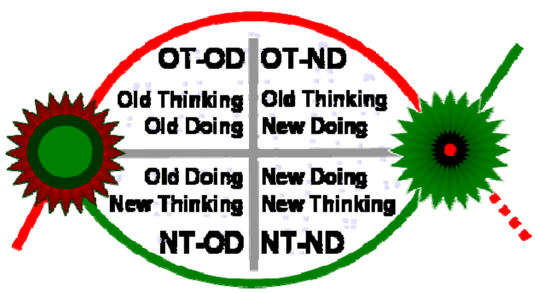

Figure 4. The lense of innovation

In order to give novel ideas a chance to develop, CST is stressing **five chaordic properties:**

Consciousness,
Connectivity,
Indeterminacy,
Dissipation, and
Emergence

The five chaordic properties and the domains of Internal/External, Individual/Collective are the properties and domains that should be considered by the IDT and POM holistic research Roadmap

Waldrop (1992, p. 11) (Section 2.1) states that **complex systems** are characterized by:
(1) **a great many independent agents** who are interacting with each other;
(2) **systemic interactions** which can lead the system to spontaneous self-organization; and
(3) **learning** which takes place through feedback.

Subsequently, the complexity (framework) is **an approach to design complex organizational systems that recognizes the enterprise not as a fixed structure, but as "flow"** (van Eijnatten, 2001; van Eijnatten and Hoogerwerf, 2000; Fitzgerald and van Eijnatten, 1998).

It offers new concepts to better understand uncontrollability, uncertainty and complexity in a "learning organization", which is described by Senge (1990, p. 3) as an organization, structure, process or network "where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspirations are set free, and where people are continually learning to see the whole together."

So, we do not focus on chaos theory – which is a mathematical construction (Weinstein, 1998) – but
we use chaos as a systemic way of looking at reality, as a world view, as a metaphor for change which recognizes that systems are complex, dynamical, and non-linear.
(Deliverable D3.17: Combined Refined Roadmap for all I*PROMS Research Areas, November 2007)

5 Radical Roadmaps based on visionary "what… if?"scenarios.

Introduction.
An in-depth analysis of previous roadmaps (outside the I*PROMS framework) for research an manufacturing, especially the long-term ones, shows that many of them have failed to predict future trends by a large margin. Typical examples include the prediction in the 1970s of slow advancement of personal computers into general use, or the prediction of advancements of artificial intelligence by the year 2000. This, of course, is not the failure of the experts who compiled those reports, but rather a reflection of the fact that in many cases research and manufacturing achievements are

unpredictable. A failed roadmap or prediction, however, is not a negative phenomenon. It still gives us valuable information (similarly to negative results in experiments), but they have limited value in forecasting and managing economic behaviour.

An approach to avoid the compilation of roadmaps which may possibly not realise is to anticipate the extensive turbulence and incorporate them into the predictions, or introduce turbulences that may not even happen. Such an approach, of course, can not produce a comprehensive recommendation on how to achieve targets in research and manufacture, but it can provide a valuable tool when attempting to react to these turbulences, should they happen.

The IDT/POM group has identified a radical roadmap based on visionary 'what-if' scenarios as one possible solution. The main advantage of such an approach is that the scenarios can be based on any sphere (sociological, economic, environmental, cultural, and ethnical) and do not have to form a coherent system. This allows great freedom in compiling a list of scenarios and the system is easily expandable.

A list of 'what-if' scenarios is provided below and the solution of how the research and manufacturing system should/could react to the corresponding turbulences. Since the IDT/POM group is now looking for general solutions outside the producer-customer framework, many of the measures are not directly IDT and/or POM related but rather reflect a global viewpoint. This is one of the strengths of such an approach.
Since the number of 'what…if' scenarios is unlimited, the following examples are obviously not conclusive and the report did not even attempt to make a comprehensive list. However, it does discuss several major problems that might affect future European manufacturing, and it does give some indications how a new type of radical roadmapping might be conducted.

5.1 … we want to reduce the use of fossil fuel by 50%?

The current large scale use of fossil fuels causes a lot of problems on a worldwide scale. The first one is the limited availability of cheap oil sources, leading to high price levels, but also to political tensions in the struggle to control the scarce resources. The second one is the environmental damage caused by carbondioxide emission and other toxic emissions. There is every reason to reduce fossil fuel consumption considerably and as sson as possible.
The main applications where fossil fuel is now used as an energy source are

- Powerplants
- Automotive
- Transportation, ships, aeroplanes.
- Houses and buildings heating.
- Chemical production, as a source of energy and as raw material.
- Industrial production in general, as an energy user.

Use of fossil fuel can be reduced by either reducing fuel consumption or by replacing fossil fuel by alternative energy sources, such as nuclear power, hydroenergy, wind, solar power or geothermical energy, of course with a preference to the more sustainable and environmetal friendly sources. Electricity is a very attractive form of energy, but not an energy source, because it has to be generated from another source.

What can the design and manufacturing community contribute to a reduction of fossil fuel consumption?

- Develop energy efficient production and manufacturing processes.
- Develop energy efficient products. Small and light products contain less material, their production uses less energy, their use is more efficient.
- Reduce logistic movements in production, eliminate transportation.
- Advice governments about feasibility of energy specifications for new products.
- Design energy efficient buildings, with minimal loss of energy.
- Develop better insulation materials and building constructions.
- Apply alternative energy sources in products and buildings wherever feasible.
- Use sustainable material in product designs. These materials should have a low energy content and preferably not be based on oil as raw material.
- Integrate sustainable energy generators in product and building designs. Example: solar panel on roofs and in calculator, sails on commercial ships.

The technical research areas for design and manufacturing are clearly recognisable in the previous points. A large effect however will probaly not be achieved with improvements of single products or processes. A systems approach is needed to achieve better results.

Finally, what do designers, architects, policy makers and manufacturers need to develop and create energy efficient systems?

- Knowledge about ways to improve energy efficiency and alternatives for fossil fuel.
- Tools to evaluate product and system designs on use of fossil fuel.
- A systems approach to use of fossil fuel. A combination of many technologies, legal and political conditions, social and econimical aspects should be the basis to allow radical renewal and achieve considerable effects.

5.2 … you want to reduce the use of non sustainabable resources by 50% in products and manufacturing.

The question here is not exactly to reduce the percentage of non-sustainable resources in products in general as this still might not lead to a global reduction. Unless the total volume of production is reduced the global resource usage might still grow. In order to maintain a sustainable level of resource usage, research in the following areas will be necessary:

- Low energy requirement manufacturing processes: near-net shaping processes, vacuum coating, nanotechnologies, …
- Low energy and material requirement products: miniaturisation helps, but is not sufficient.
- Recycling
- Product re-usage
- Cultural change to reduce overconsumption
- Reject paradigms that promote overconsumption: consumer-based design, consumer-driven design, mass customisation, time-to-market compression, rapid manufacturing, concurrent engineering and others all focus on company success, namely producing/selling as many products as possible. This naturally leads to overconsumption as consumers tend to discard products long before their useful lifetime expires.

5.3 … Asia forms an economic union like the EU?

It is interesting to speculate about the effect of "Formation of an Asian economic union similar to the EU" on the future of manufacturing within Europe. In order to predict the effect it is important to predict the changes within Asian countries in the first place, and then predict its effect on Europe.

Currently some Asian countries have several economic cooperation's like:
The Association of Southeast Asian Nations (ASEAN) political, economic, and cultural organization of countries located in Southeast Asia (Myanmar, Laos, Thailand, Cambodia, Vietnam, Philippines, Malaysia, Brunei Darussalam, Singapore and Indonesia);
South Asian Association for Regional Cooperation (SAARC), which focuses on cooperation in agriculture, rural development, science and technology, culture, health, population control, narcotics control and anti-terrorism within 8 countries (Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka and Afghanistan);
Closer Economic Partnership Arrangement (CEPA), an economic agreement between the People's Republic of China, the Hong Kong SAR government, and the Macau SAR government, in order to promote trade and investment facilitation and eliminate tariffs and non-tariff barrier on substantially all the trade in goods between the three, and achieve liberalization of trade in services through reduction or elimination of substantially all discriminatory measures;
These agreements are related to the geographically closer or neighbouring states making limited economic growth of particular region within Asia. Though having these co operations, they lack Free Trade Agreement at a broader continent level. This along with the majority of the states still categorized as "Developing Nations" makes the cooperation weaker as compared to the European Union.

Formation of an Asian Union similar to the European Union might bring the following changes in the Asian countries.

Stronger Economic Growth: As the economy of certain European states like Germany, France, Italy had a reasonable growth after joining the EU similar economic growth might be expected in the developing states within Asia. If an approximate growth of 2.00% - 2.5% of Asian countries is realised it might get them closer to the growth of Europe and that of USA.

Changes in Laws: Countries in Asian Union will have the same policies on trade, industry, employment and consumer affairs, which will give the same benefits to businesses, consumers and working force throughout Asia. All the Standards of products and services will be harmonised regardless of where they are produced or offered within the continent.

The world's largest internal trading market: The Asian union is formed of 46 member states with the population of 4 billion, which is around 60% of world's population, will make the AU the world's largest economic trading zone (including largest economies like China, Japan and India), surpassing the trading capabilities of European Union. The AU will abolish the border control, which will result in the reduction/elimination of costs incurred in cross border trade to the businesses. This will also enhance the movement of goods (reduce the time) and people through the continent.

Greater Competition: The internal trading market which will be a single market. It will eliminate all the anti-competitive practices like monopolies, cartels, etc. from the market. This will have further reduction in costs of the products/services and allow more companies to operate in the market and give consumers a greater choice of suppliers/places to buy the products and services at a better price.

Increase in employment: Single market and increase in competition will increase the trade within the continent and this in turn will enhance the growth of the employment and hence increase in the GDP of the AU countries.

The changes in the economic conditions of the countries in Asian sub continent will definitely have an impact on the future of manufacturing within Europe, as listed below:

- As a result of increased competition and internal trading market; there will be more manufacturing companies in the Asian continent that will be able to produce goods with the further reduction in the prices. This will in turn increase the amount of manufacturing being outsourced to them.
- There is a possibility that with remotion of trade barriers the amount of trade within the Asian continent will be higher than expected and it will just be able to meet the needs of the continent at first place. This might have an effect on the quantity of export. With such conditions the manufacturing within Europe could increase to fulfil the demands of the EU states.

With the increase in economic condition of the AU countries; there will be more employment with in the population and an increase in their spending capacity. This will lead to the needs of improved life style for the people of the developing nations. Nations as a whole will have sufficient funds for the infrastructural development of the nation. So at both an individual level and at a national level; there will be the need of more advanced products/services. And many of the EU countries being developed and having the capabilities and technical know how for these products and services, will be able to offer it to the developing countries in AU. This will enhance the manufacturing and related services businesses within Europe.

* Compiled from:
European Union Membership - The Benefits, Department for Business, Enterprise & Regulatory Reform, http://www.berr.gov.uk/whatwedo/europeandtrade/europe/benefits-eu-membership/page22676.html

So, what has Europe ever done for us? Apart from..., The Independent, http://www.independent.co.uk/news/world/europe/so-what-has-europe-ever-done-for-us-apart-from-441138.html

5.4 … unemployment is resolved?

- **How/why would designing and manufacturing work opportunities develop to lead to this situation?**
  - The designing and manufacturing tasks require both, skilled and unskilled labours.
  - The increasing population and globalisation of trading have created a global customer base.
  - The economical reforms help set up better infrastructure to product designing processes and manufacturing plants. In countries like China

and India, which are the new manufacturing hubs with cheaper labour and manufacturing costs (as compared with developed nations of Europe and the United States), these reforms create new demand of skilled and unskilled workers, such as designers, plant managers, accountants, machine operators, mechanics and even construction engineers and labourers.
- Also, this situation requires more industrial researchers in both, developed and developing nations.
- New innovations, fast technological growth, changing life-styles and customer desires have created great demand of "customized" products in many areas.
- All these factors state that there is a new special kind of demand of design and manufacturing workers who can efficiently design, prototype and produce highly customised products in whatever quantity.

- **What would have been an approach to meet the type of demand mentioned above?**
  - To produce a product any time (high demand), anywhere (globalised demand) a suitable approach would be to have ubiquitous manufacturing systems.
  - To enable the available human force to produce customized products, there should be cheaper machine tools which could be affordable by a large number of producers of any scale.
  - Better designing of tools to create rapid prototyping and more innovative designs for better customization of products.
  - Better networking of suppliers and customers, technologically and logistically.

- **How productive/efficient would the designing and manufacturing workers be, following the above approach?**
  - As the new infrastructure will be established, there will be better management and administration of the production life cycle.
  - Better networking will give agility and dynamism to the design and manufacturing processes.
  - Since the "people" will be equipped by (modelling, machining and networking) means, they will be able to create the products as per the demand in a much more rapid way than presently.

- **What will be the issues while trying to best utilize the employed skilled/unskilled workers to increase the productivity and form a stable economy?**

  - One possible scenario is, that there will be much more producers than at present, such that the "growth rate" in the number of producers will outnumber the current growth rate in the number of customers.

- While this will generate more product supply than presently available, to satisfy all feasible product demands, it will also create a very highly competitive business environment.
- There will be less profiting, than at present, because of the smaller quantity produced by each supplier/producer and due to the higher levels of competition.

5.5 … we want to provide enough sweet water for the world population?

According to some analysts, the next global war might well be not because of fuel or other mineral resources but over sweet water. Although the total amount of sweet water would probably be sufficient to comfortably support the current population, the uneven distribution of rainfall makes this problem more and more difficult to solve. Research in the following areas will be necessary:

- Water pipelines similar to oil and gas pipelines to transport water from wetter areas to the regions in need. This is a much more ecologically friendly solution than recent attempts to transport icebergs (across water) as it does not significantly hinder the natural sustainability of the planet.
- Research in water management technologies.
- Cultural change: to save water, to prevent overconsumption
- Reduction of the use of purified water in applications and industrial processes.
- Regulations and incentives: to save water
- Reducing water leakage

5.6 … the population rises above 15 billion by 2020?

In recent publications it has been highlighted that given the current lifestyle of Western Europe and the United States the Earth could comfortably sustain no more than one billion people. Sustaining the current population of about 8 billion is only possible at the moment because most of the Earth’s population is living in much worse conditions than those in developed countries.

According to even conservative estimates, the population by 2020 will reach 15 billion before it eventually starts to drop. It is obvious that unless the division between poor and developed countries is maintained (which can not and should not be the aim of any society), there can be only two solutions to this problem: reducing the Earth’s population and/or changing the lifestyle of people. The research needed in this area is well outside the scope of IDT and POM. However, certain measures in these areas can still be effective.

Research necessary to deal with problems of overpopulation and over-consuming:

- Cultural and behavioural studies: these are obviously non-technology related issues and the inclusion of a much wider community of researchers (including psychologists and even spiritual leaders) is needed. Apart from the obvious task of controlling the growth of population through persuasion and birth control, cultural and behavioural studies for changing lifestyle and consuming patterns is vital.

- Promote standardisation: fast-changing standards and parallel standards for identical or similar products and services specification promote fast obsoletion of products.
- Paradigm change to overcome the age-old false feeling of consumer-producer satisfaction. Unless satisfaction is achieved at a much larger scale (outside the limited consumer-producer community of a given product), this satisfaction is false and not justified.

5.7 … economic recession hits the world for the next five years? How should the manufacturing world respond?

One of the aims of the creation of the European Union was to tackle problems connected to the turbulences of the world economy. The strength of a larger community, similar to that of the USA, should help overcome problems that individual member states themselves would not be able to solve. However, recent events clearly show that economic recession in one region (like in the USA) can still make the EU economy vulnerable.
In recent years there was a tendency for outsourcing production to Asian and other poorer countries. While the reason behind this is understandable as it leads to reduced cost due to cheaper labour in those countries, the effect it has on European manufacturing makes the economy even more vulnerable during recessions.

- Research in ubiquitous manufacturing systems
- Cultural change: to convince people not to opt for low quality but cheap products, but to prefer local production even at higher cost.

6 Conclusions

Future research in manufacturing and design technologies should be multidisciplinary. A purely technical approach is too limited to solve the future problems. Technology and technical innovation can and must contribute to solve major challenges and create breakthrough improvements, but can only do so if the proposed solutions are acceptable for society, law, and politics. Very often real innovation is restricted by these factors. Therefore non technical disciplines like psychology, economics, medical and behavioural sciences, law and cultural studies will have to combine their strengths to achieve an integrated approach to system innovation and renewal.

Conventional roadmapping is based on extrapolation of the current situation. Therefore it is by nature limited in its ability to forecast unforeseen situations and will not indicate radical system transformations. An alternative is proposed by Radical Roadmapping which is based on the idea that companies and society are dynamic, turbulent and unpredictive. System innovation is considered to be a linear process followed by first stagnation and than a breakthrough period in which new ways of thinking and doing emerge. These can only be successful and sustainable if they are acceptable for consumers, society and the environment.
The IDT/POM team has used a Radical Roadmapping approach based on visionary “what... if scenarios”. It presents a new additional approach for defining the research agenda. Instead of attempting to provide a deterministic approach for defining the research path, it provides a methodology for defining research directions for in deterministic and unpredictable scenarios in turbulent environments.
It is recommended that at least part of the future research agenda allows for the Radical Roadmapping approach, as it is considered to be very useful and complementary to conventional roadmapping.

Future product innovation will be characterised by further miniaturisation, increased functionality, integrated intelligence, global application and the combination of physical products with services. Technically these products will be the result of multidisciplinary design, including mechanics, electronics, software, biomedical and materials disciplines. Product life cycles will be shorter and products will be more individualised. Mass customisation will lead to individual products against low costs. Manufacturing technologies such as Rapid Manufacturing will enable efficient one-off production, and will further develop.

Product information and product information management will become very important. Because of product liability the traceability of products will be further refined and imposed. This trend, combined with the increased variation in products caused by further individualisation will lead to a huge increase of product data and a big challenge to manage them.

Design and manufacturing will become more and more global and distributed activities. Collaborative design will be carried out by international design teams in which both professional designers and engineers as well as users and consumers will have a role. Virtual cooperation’s will emerge to carry out projects. It will be an important challenge to manage the flow of information, and the logistics of the physical products and materials. New working methods must be developed to bridge the difference in time as well as the cultural gap for globally working teams. For manufacturing a similar trend is taking place. Flexible factories, working together in a specific supply chain for each new product will have to be very adaptive to meet the dynamic demand of customers. Ubiquitous manufacturing is geographically distributed and very small scale factories might play a role in this.

Design methods should lay more emphasis on sustainable and responsible use of resources. Energy is already an important topic, and water is expected to be an issue in the near future. Future products and technologies should be very energy efficient and use minimal non sustainable resources through their complete life cycle. Possibly this might lead to the need for longer product life cycles, although this is contrary to a high innovation speed. It is necessary and will be imposed that products should be very fit for recycling.

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8 References

J.P.Martino, Technological Forecasting for Decision Making, McGraw-Hill, 1996
http://www.delphistudy.org/about.html
http://www.dse.vic.gov.au/DSE
Westkämper, E. (2006) New Trends in Production. In: Dashchenko, A.I. (ed.) Reconfigurable Manufacturing Systems and Transformable Facotries. Springer Verlag,Berlin Heidelberg New York, pp 15-26
Nyhuis, P., Denkena, B., Wulf, S., Blümel, P.: Integrative Factory, Technology and Product Roadmapping. , (2007) 2nd International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2007), 22-24 July 2007, Toronto, Ontario, Canada, S. 232-240, 2007

References (Radical Roadmapping)

Eijnatten F., Putnik G. (Guest Editors) (2004) *Chaordic System Thinking for Learning Organizations*, , Special Issue of "*The Learning Organization – An*

International Journal", Publisher: Emerald, Volume 11, Number 6, (October) 2004.

Eijnatten F., Putnik G., Sluga A. (2007) Chaordic Systems Thinking for Novelty in Contemporary Manufacturing, *CIRP Annals*, Vol 56, No 1, pp. 447-450

Falkenberg, E. D. et al. (1998). *A framework of information system concepts — The FRISCO Report* (Web edition), FRISCO, IFIP. Available online *ftp://ftp.leidenuniv.nl/pub/rul/fri-full.zip*

Hesse, W., & Verrijn-Stuart, A. (2000). Towards a theory of information systems: The FRISCO approach. In *Proceedings of the 10th European–Japanese Conference on Information Modelling and Knowledge Bases* (pp. 81-91), Saariselkä, Finland. Presentation of the paper available online *http://www.mathematik.uni-marburg.de/~hesse/papers/FRISCO.pdf*

I*PROMS (2007) *Combined Refined Roadmap for all I*PROMS Research Areas*, Deliverable D3.17: November 2007, pages: 86.

Liu, K. (2000). *Semiotics in information systems engineering*. London; New York: Cambridge University Press.

Love T. (2000, May). Philosophy of design: A meta-theoretical structure for design theory. *Design Studies*, 21(3), 293-313.

Moor, A., & Weigand, H. (2002). Towards a semiotic communications quality model. In K. Liu, R. J. Clarke, P. B. Andersen, R. K. Stamper, & E. -S. Abou-Zeid (Eds.) *Organizational semiotics: Evolving a science of information systems* (pp. 275-285). Dordrecht: Kluwer.

Putnik G. D., Cunha M. M., Sousa R., Ávila P. (2005) Virtual Enterprise Integration: Challenges of a New Paradigm, in Putnik G., Cunha M. M. (Eds.) *Virtual Enterprise Integration: Technological and Organizational Perspectives*, IDEA Group Publishing, Hershey, PA, USA, pp: 1-30 (ISBN: 1-59140-405-3; ISBN: 1-59140-406-1; eISBN: 1-59140-407-X)

Stamper, R. (2000). New directions for systems analysis and design. In J. Filipe (Ed.) *Enterprise information systems* (pp. 14-39). Dordrecht: Kluwer.

Stamper, R. K. (1996). Signs, information, norms and systems. In B. Holmqvist et al. (Eds.) *Signs at work*. Berlin: De Gruyter.

Szecsi, T. and Putnik, G., (2008), "The Effect of Consumer Satisfaction on the Environment", in *Proceedings of the Business Sustainability 2008 International Conference (BS08), Ofir, Portugal, 25-27 June 2008*.