Outlook Report on the Future of European Assembly Automation

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INTRODUCTION

This Roadmap is primarily concerned with the adaptive assembly technology situation in Europe, a topic of particular interest as assembly is often the final process within manufacturing operations. Being the final set of operations on the product, and being traditionally labour-intensive, assembly has been considerably affected by globalisation. Therefore, unlike most technology roadmaps, this report will not focus solely on particular technologies, but will strive to form a deeper and broader perspective on the conditions that may come to influence our opportunities, including political aspects and scientific paradigms.

The goal of this endeavour is, therefore, to convey a complete view of the global mechanisms that may come to force or hinder technological breakthroughs, and also attempt to present strategies that may assist European industry & society to better prepare for such a forecast.

Perspective

Technology is often viewed as either the means by which we may solve global problems, or the reason for which we have several threats. Whichever party one may chose to adhere to, the common denominators are that technology does not exist as a separate entity within our societies, and neither does it leave them unperturbed. Therefore, it would be a gross mistake to carry out a roadmapping activity without studying and analysing a wide range of societal, ecological, political and other factors. In order to achieve a clearer understanding of what our future may hold in store for us, the EUPASS Roadmap has therefore reviewed several existing roadmaps [1,2,3,4] from different disciplines, and also carried out its own studies on a broad perspective. There seems to be a general consensus as to which technologies will come to dominate in the next decade, at least in terms of commercial application. What does seem to be lacking from other roadmapping and strategic overviews, however, is a better understanding of how this may become industrially viable, all the while maintaining the vital sustainability criteria: these technologies/products will have to be produced in a sustainable, cost-effective, fault-tolerant manner. The “how” aspects become rather vital. Therefore, this Roadmap will delve somewhat deeper into the fundamental mechanisms that may allow European industry and society to achieve the required breakthroughs in assembly. Details on the technologies that may result in quantifiable market shares will not be stressed.

Context

Let us be certain of one fact: the context is changing rapidly. Automation will become more vital for Europe for a variety of reasons and for most manufacturing sectors. This will be explained by the demographic studies, production approaches, and dynamic demands. This is often concealed in the results attained by many roadmaps [1,2,3,4,5,6] as the topic sustainability. This objective is, however, multi-faceted:

• the solutions need to be sustainable from an economical point of view as the companies need not only acquire the manufacturing technology, but also maintain it. The production technology not only becomes intertwined with the product itself, but with its workforce potential as well! This entails sustained economic viability and technological know-how.
• there are ecological aspects linked to sustainability [7]: minimise use of resources & unwanted materials, waste disposal, pollution, etc. This issue has been recognized to be one of the most pressing factors because resources are dwindling and because of a huge pull of resources to China and India.
• societal aspects must also be brought into the picture, as the technologies in question need to support and sustain the societies and economies being affected by them: a common example is that automation will cause rapid job turnovers at shop-floor level, demanding higher quality/skilled labour at a time when it is becoming scarce, but it may also create new employment in the form of equipment suppliers, programmers, maintenance personnel and other services.

Therefore sustainability acquires also a ease-of-use dimension, including the maintainability aspects. Hence the sustainability goals. The general understanding of what is of interest is best portrayed by a quick analysis of the given scenarios:

Scenarios that depict situations which most users can recognise themselves within are to be focussed on to avoid local solutions that become less agile and, therefore, suited for a smaller community of users.
Scenarios which accommodate an adaptability to both technological and market situations are favoured.
EXECUTIVE SUMMARY

The obvious conclusion is that the context is changing and that future manufacturing will have to deal with very complex scenarios. Furthermore, the impact of automation, for Europe, will inevitably affect all of the manufacturing sectors (e.g.-the shoe industry has automated considerably). This Roadmap will therefore cover many topics that are generally not analysed in conventional technology roadmaps. The intention is to convey, through this document, that for future automation technology, multidisciplinary efforts are not only required to succeed, but must also be understood: once again, it may be of greater interest to delve into how it may applied successfully rather than stating what should be included. This is clearly underlined in a major industrial document [8], in which the authors point out, after a major study, that:

"perhaps the key threat to the long-term prospects of complex systems research is the instability of interdisciplinary research".

Basically, the broader picture needs to be well understood if one is to succeed in developing solutions for a highly dynamic, global economy in which the political, ecological and social changes play a key role. The following chapter will give a short review.

- Management retains a short-term perspective on strategies, and more production-based, or technological understanding is demanded at European management level.
- Many existing and emerging products require micro assembly, although the bulk of the profits are still made by macro products. Scenarios for smooth transitions are required, and do not need to be prevalently directed to only micro or nano.
- Production and/or manufacturing still lag in terms of exploiting IT solutions, and the world has, for quite some time now, been engaged in a globalisation phase: all aspects of a company need to be dynamic.
- Approaches to system development need to radically change, adopting more holistic, IT-based methodologies.
- Supply chain, sub-supplier negotiations, product development, marketing strategies, are all becoming more dynamic & intertwined. Hence the need to dynamically connect all levels of operation and allow for rapid and smooth collaboration.
- Europe is entering an age of decreasing labour forces and new member states. These new member states will denote positive birth rates and larger labour forces, all the while maintaining lower wages in the short-term. European population levels will never double, rendering Europe a minority and multiethnic continent.
- Regulation will, most probably still denote a habit of rapid changes of direction and variable focal point. EC Regulation needs to be more technologically balanced and righteous, rather than politically correct on the short-term.
- The world competitiveness is increasing while the eligible markets are growing. This also exists whilst there is a final, at times desperate race for the natural resources needed to sustain such developments. This poses conflict threats.

The result is that production needs to adapt very quickly to all sorts of changes and that products need to reach markets immediately. In this light, rapid deployability and effective adaptability are considered the main targets for any endeavour to attain true sustainability: assembly and markets need to dynamically evolve in economical & ecological harmony.

The Big Picture

The following details were developed by a panel of experts to try and pinpoint a wide range of aspects that have a clear impact on how technologies are assimilated and exploited. The results were screened by industrial reviewers and compared to the results of more elaborate studies in each category. The intention is to go beyond a clear statement of where technology is today, and where it might be in 2010-2020: the long-term innovation cycles of companies demand a broader picture, in which management, social issues, ecology, regulations and other factors play a vital role. Therefore the intention is to attempt to:

- consider "simple" technology as seriously as the forecasted key technologies.
- consider social and ethical factors which may be acting as showstoppers or catalysts.
- pinpoint the hidden drivers behind the transformation of industry.
- analyse the sustainability issues that may come to modify our market needs.

Note that the study identified serious political threats that may come to slow down or fully halt any form of development: fresh water crisis, battle for natural resources, recurrent financial turmoil, and political nonchalance of global warming/dimming. These issues are extremely complex and fall beyond the scheme of this report, but the reader must remain very aware that the global dependence on nonrenewable resources is one of the largest threats for future prospects. Hence, the major opportunity: sustainable, ecologically-oriented solutions, which are needed most urgently, may lead to new market opportunities, services and economies.
**THE INDUSTRIAL & TECHNOLOGICAL SCENARIO**

**R&D Issues**

**Product Lifecycle uncertainties**
Product lifecycle uncertainties are a consequence of several problems (lack of process knowledge, etc.), and others which have not yet been well documented. The symptoms manifest themselves in very low assembly system adaptability to product and production variations, the inability to forecast product changes in time, etc.

The somewhat hidden problem, however, is that the major part of producing companies have to deal with planned products and existing production facilities. Ideally, they would like to fit any new product, or product variant, into an existing assembly system with as low costs as possible. To date, this has only been a dream. The common scenario is that the existing production system principles still dictate, to a varying degree, the basic design requirements for future products, and vice versa. Basically, there is a strong dependence between product development and selected system principle (parallel flow, serial line, etc.).

This entails that any new assembly system solution has to fit into an existing facility, even though this facility may denote performance limitations. The same applies for a new product design.

For example, as soon as a new product design is assumed to require a new assembly system solution, a serious analysis of the required components is needed to ensure that the targeted volumes, costs, etc. are attained. This often leads to a change in some system component, or product part, to enable the achievement of the goals: sub-optimation. Such practical approaches lead to equipment that cannot easily adapt to changing market requirements and/or new products: the overall adaptability is greatly reduced.

Once again, the creation of low-visibility micro & nano-factories will, in time, lead to an amplification of these issues.

In other words, micro & nano-factories are not exempted from the basic nature of current production principles. Micro & nano-systems will require a re-consideration of all known product and system design methodologies and approaches.

In order to reverse these negative trends, a new methodology which encompasses all phases in a product lifecycle is required. This goes beyond linking product design and system design.

Another major problem is that current control/supervision architectures are not efficient: any change or addition made at shop-floor level requires programming modifications (production downtime). This implies that qualified programmers must be called in since this competence is seldom found within producing companies, let alone SMEs. To worsen the situation, such program modifications (even small changes) might affect the global system architecture, therefore causing an increased programming effort and the potential for unwanted side-effects.

It is therefore mandatory, in order to enable efficient re-engineering practices, to develop approaches to eliminate or reduce these problems. These should focus on configuration, rather than codification issues[18].

**Weak link between Product & System design phases**
Product design and production system design are two phases that, albeit the major efforts made in recent years, still denote a very weak link. This is primarily due to the fact that the processes being catered for in the assembly systems are not well documented or structured, but also due to the fact that tools such as DFA and others do not really integrate an adequate feedback loop from the system developers. The designers are usually oblivious of which system solutions are available for which processes, and the system vendors/developers do not subdivide assembly into processes but, rather, into tasks to be performed. That is to say that there are several parameters and/or attributes to a simple task such as “glue dispensing” that may be omitted if the task is not turned into a process (i.e.- ventilation, glue film thickness, hardening times, etc.). Such detailed aspects are often neglected by the system vendors, which “fix” the system solution on-site at the last minute. The critical issue here is that these process details, along with specific details linked to particular materials, tools, or other components, usually never reach the product designer’s toolbox.

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**Fig.6- Example of a micromotor (Courtesy of Maxon Motor AG)**

Diameter = 0.6 mm
Length = 22.5mm
Such a weak link between two major design phases will become a huge problem in the future since, as products get smaller, the process details become even less visible, and the original problems will become greatly magnified.

The priority of this problem area is high, and can be well-documented by the differences denoted in company strategies. Companies such as Sony and Nokia have based most of their product development upon these methods. The resulting success of each of these companies in maintaining production competence, and in attaining market shares and rapid responses to market demands, is known.

Another aspect is the growing need to place the orders within final assembly: Assemble-to-Order. The main objective here is to shift the point of variance as late as possible within production: create the final product identity as late as possible. It is, therefore, of vital importance to simplify final assembly as much as possible. In order to achieve this, very robust product design – assembly system design couplings need to be attained.

In order to illustrate this problem area, one must also consider that "low visibility" in micro or nano-factories also implies functionality losses. This is a known problem in miniaturisation and consists in the difficulty of applying all the required functionalities into a physically diminishing object. A typical example may be the need for electrical contacts on a micro-sized manipulator. One must recall the fact that these micro-factories will have to perform as normal factories from a production point of view, with information exchange, control system structures, product flow monitoring, etc. The problems that will arise at production level will have to be fed back to the factory & nano-product design teams. If these problems are not "visible", the resulting deterioration of the product design – assembly system design coupling is obvious.

In order to force R&D work into the correct direction, aspects such as system autonomy and the validation of stable processes must be included into future efforts.

**Lack of Effective Cost Models**

The risks and uncertainties associated with selecting the correct assembly system for a given product/product family are also connected to the lack of efficient investment/cost analysis models. Selecting the most adequate assembly system approach is a complex matter due to the fact that the factors influencing the choice are many and not all well defined. These may include cost, complexity, labour agreements, legal issues, safety, logistics, market volatility aspects and many more. Furthermore, in order to better understand and control the cost mechanisms that affect assembly, there is an urgent need to create and apply assembly performance tracking tools throughout the product lifecycle.

Cost issues are of great importance since their understanding must be spread to a wider audience within a company. Likewise, the potential long-term benefits of an automation solution must be made economically clear to the decision-making people of a company. This is not as obvious as it may seem, as modern production systems are constantly affected by a wide range of factors that require immediate production response. Basically, if one fails to mathematically model the dynamic functions that affect our assembly/manufacturing needs, any attempt to derive cost models will fail. *Traditional approaches no longer hold: there is an urgent need to develop analytical methods that enable one to formalize the driving economic factors that influence the specific needs for dynamic change.*

**Outsourcing**

The outsourcing trend has led to a flourishing business for "contract manufacturers", companies that offer to produce part, or entire ranges of, products. These conduct insourcing strategies. What basically happens is that a major company outsources manufacturing and most of its assembly to a specialised contract manufacturer.

This trend is particularly strong in the telecom and electronics segment of industry, industrial branches which are the most likely to benefit in micro and nanotechnology advances.

The lack of a clear understanding behind the benefits and losses, risks and economical implications behind outsourcing have NOT been well-documented. A greater part of the implications of outsourcing, such as new logistic costs, floating stocks, WIP aspects, have not been well analysed. Due to this fact, decisions to outsource are taken on loose grounds.

Analyst IDC reported that the total value of the 100 largest European outsourcing deals signed in 2003 increased from $19bn to $44bn [11]. Outsourcing is increasing, and, if analysed by sector, governments are found to have committed most heavily to outsourcing. Of course, not all outsourcing is detrimental, and in some cases may also be beneficial: if one only looks at the short-term customer aspects, then quicker delivery, cheaper prices, and wider availability might sound compelling. However, one must take a close look at what is being outsourced, in which way, and at which rate.

The outsourcing problem is real: McKinsey & Co., the USA, Europe and Japan are losing approximately 600,000 jobs/year within the manufacturing sector, a fact rendered even more serious by the Gartner Inc. study, which notes that this trend is likely to maintain its course until 2010 and result in the loss of 25% of high-technology jobs to emerging markets in India, China, and elsewhere[13]. According to Forrester

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1. UK dominates European outsourcing spend; Robert Jaques, vnunet.com 30 Apr 2004
Research[14], 150,000 IT jobs will have moved outside Europe by 2015. The figures given relate to the outsourcing of manufacturing operations. Within these, there may be a series of operational classes, ranging from final assembly to product design. However, outsourcing has now gone as far as to include R&D operations, which is particularly alarming as this may be deemed as the intellectual infrastructure upon which most European manufacturing companies rely upon.

Fig.3.0- Rate of Outsourced Jobs (% of European Total)

The European Association of Contract Research Organisations launched a particular concern: “Governments, too, need to respond to the changing world of industrial R&D. At European, national and regional level they need to review their R&D and technology policies and programmes to ensure that the growing trend towards outsourcing research in its various forms can be fully and fairly accommodated within them. Governments have a duty also to ensure a level playing field for all contestants...Failure to do this can only result in sub-optimal economic efficiency and wasted public resources.”

Most arguments for and against outsourcing seem to focus on short-term validation data: manufacturing is losing jobs, service sector is gaining them, there is an obvious shift to a service society, etc. The interesting point is being missed as the basic essentials of what constitutes a successful product are being handed over, and if even our own future concepts and research results are made openly available, then it does not require great forecasting to imagine the outcome in the long-term: an industrial society cannot survive on services alone, especially if 93% of its manufacturing force is SMEs with marginal competitive strength on a global scene.

The lack of a clear understanding behind the benefits and losses, risks and economical implications behind outsourcing have NOT been well-documented. A greater part of the implications of outsourcing, such as new logistic costs, floating stocks, WIP aspects, have not been well analysed. Due to this fact, decisions to outsource are basically taken on loose grounds. But this is NOT the worse aspect. Note that outsourcing assembly also implies the handing-over of quality settings, supply chain setups, and design issues. This implies the loss of responsibility and the eventual take over by the Contract Manufacturer. And this is actually becoming a sought-after business strategy (see below)!

The danger is that the original company is basically outsourcing the process knowledge. This has been well pointed out by Austin Weber [15] in his interviews with US companies: “Manufacturing engineers need to be aware of several disadvantages associated with contract manufacturers- you are losing control of manufacturing; Gartner Group, Tomasz”. This is primarily due to the fact that the OEM and contract manufacturer have divergent goals. Note that contract manufacturers do not want to be termed as such, and prefer to refer to their companies as “Manufacturing Services” providers. Their final intention is to make a wider contribution to the whole process: from product design (!) to manufacturing execution. This often leads to a gradual process knowledge breakdown at the original company, which, in time, leads to a loss of product know-how, market shares, etc.

In fact, the Contract manufacturers are more than willing to take over even the product innovation aspects. This is confirmed by a recent article in ZDNet.co.uk which illustrates how Managers today even see it as a strategy to hand over product innovation to these Contract Manufacturers (!): "The difference with outsourcing now is that companies... want to see providers coming up with more innovation, they want to see a transformation of what is being outsourced."

2 THE CHANGING WORLD OF INDUSTRIAL R&D: THE CHALLENGES FOR INDUSTRIAL RESEARCH AND TECHNOLOGY ORGANISATIONS AND GOVERNMENTS; European Association of Contract Research Organisations
Lack of Process Knowledge

One of the main issues to arise out of the discussions conducted at international meetings is the lack of understanding of the assembly process itself. No serious efforts have ever been made to clearly detail and structure any of these (many) assembly processes, which implies that no scientifically validated process knowledge is ever exploited during the product lifecycle. Such process knowledge is fundamental, and affects the optimisation of the product designs, eco-sustainability, maintenance, supply-chain, and the processes themselves.

The only people that really acquire any process knowledge are the assembly system operators and the people that install such systems. This knowledge is rarely documented or safeguarded through explicit procedures.

Since most of the assembly process knowledge is acquired and held by the assembly system installation personnel and system operators, there are some threats that could worsen this scenario considerably. One of these trends is outsourcing, a strategy used to curb costs and focus on what companies call “core competencies”.

The conclusion is that this trend critically weakens the process knowledge know-how at the original company site.

If most of the contract manufacturers were European, this problem could be reduced. The problem is that the most successful contract manufacturers are NOT European and that almost all of these actors actually perform the assembly tasks in low-wage, non-western countries. That is to say that the trend is to transfer assembly process know-how to low-wage, non-western countries.

This instability provides an ever weaker base for feedback to the users and producers of such systems. Micro and nano-factories are also extremely miniaturised, which reduces the visibility aspects: it is not only harder to perceive what is occurring, it is also much harder to track and/or verify the events.

Finally, the underlying menace that may well amplify these threats in an alarming manner is the rapid decline in workforce in Europe. The forecasts produced by the European Commission clearly indicate that there will probably be no available manpower for industry within 5-10 years.

This implies that European industry either outsources all of its production, creates a large immigration wave, or automates its production. In terms of social and technological reasons, the latter is strongly recommended.

Other process aspects

Current DFA tools denote a lack of robust, structured assembly process models. Such process models could enable product designers to understand the implications their design have on the assembly system selection during the product design phase itself [19]. This could be developed as far as to form a coupling between materials, design and assembly processes.

The integration of different design methods into a single tool has already been identified as an area of concern in South-East Asia. Projects to deal with this have been initiated overseas[20].

Certain assembly processes seem to denote particular quality and cost problems: Joining processes affect quality due to variations in the actual fasteners and/or the special joining techniques adopted. These special techniques include adhesive joining, welding, brazing, soldering and laser deposition: these processes are not well understood and result in quality problems. Micro parts handling and positioning are also problematic assembly processes, and continued efforts are required. Furthermore, design trends, which aim at minimising the use of fasteners affect, unfortunately, the disassembly of the product. Hence the need of cost-benefit evaluation methods.

Feeding has always been a problematic process within automatic assembly, and will remain to be so for micro-assembly. Within the electronics segment this has been reduced by the introduction of tape-feeding (blister tape, gel-pack, etc.) and other similar approaches, but this will definitely be inadequate for the micro-mechanical and opto-electronic segments. Vision-based feeding and other flexible feeding approaches are required. This includes the link between feeding and joining, with particular attention placed on the interfaces required for achieving modular system architectures.
These problems are obviously greatly magnified by the advent of micro & nano products in which other forces and effects start to manifest themselves.

**Lack of Standardisation**

The standardised solution must present concrete solutions to specific assembly problems: solutions for special tooling and/or special operations must be offered. As pointed out in some of the literature [6], this precludes a thorough study of the assembly process, the equipment, the parts design and the control system.

Note that the standardisation being mentioned here relates to the creation of assembly equipment which has been developed out of a stringent classification and structuring of the assembly process. The solution refers to an open system into which new equipment may be brought as long as it follows the delimitations and interfacing requirements.

The benefits to be gained from a standardised solution are many, amongst which one may name the following:

- Shorter installation times.
- Lower investment costs and related risk factors.
- Simpler re-configurations of original layout.
- Second-hand market for equipment.

In a world in which product lifecycles are ever shorter, such an approach would render the ensuing changes in production flows and sequences far simpler and faster. The application of standard interfaces is another key factor. All in all, the time between a company’s decision to invest in automatic assembly and the actual production start would be greatly reduced.

Industrial efforts in the field of standardised assembly solutions have been presented by, amongst others, SONY FA, Flexlink Automation OY, GWS Systems OY and the Feintool Modutech concept. All of these solutions include standard robot cells and transport units as part of the system. The robots may not be changed according to the product/production requirements. Control, small-batch, and product span limitations still persist. Apart from Modutech, these solutions often refer to the modularisation and standardisation of manual assembly lines. Important improvements towards standardised interfaces and suitable control solutions have been presented by these solutions, all of which remain in-house standards. None of the solutions address the miniaturisation of products. These solutions refer to particular market areas (medium-high volume) and do not attempt to offer a general, assembly process-oriented solution. True standardisation should attempt to create system components in such a way that any assembly equipment may be integrated within any other assembly equipment. This entails that mechanical, electrical,
pneumatic, electronic and software interfaces must be standardised, be of a common format, description, etc., and allow the transport of the particular medium (software, air, etc.) without adjustments.

This also entails that the physical dimensions of the particular equipment are such that the unit may be inserted into any assembly system without requiring particular modifications. Hence, standardisation must be carried out on different domains. The Surface Mounted Technology (SMT) industry is the best benchmark in this domain. The SMT community has achieved market dominance and lower production costs through its standardisation efforts. This could be done for micro-assembly and the benefits have been well-detailed by Dr. Hans Erne\(^3\) (see figure 10).

Another problem is that the lead times for the final assembly systems will depend on the bottlenecks in the different user and supplier companies order books: if full, the delivery time will be long. This renders the issue complex because suppliers, software developers, equipment manufacturers, etc., including competing companies, must be brought together to establish the best approaches & solutions, which entails that collaborative networks may be required to solve this problem. In other words, this is standardisation of an entirely different nature (communication protocols, ontologies, etc.).

**Misuse/Lack of Maintenance aspects**

The major problems incurred by companies dealing with assembly mainly relate to uncertainty. First of all, it is very difficult for companies to predict the type and range of products that will have to be developed. The second uncertainty regards the production volumes and lifespans reached by these future products. Finally, the ultimate performance of the assembly system can seldom be guaranteed to be satisfactory, primarily due to the fact that it is a prototype [21]. The first two problems relate to the issues described under lack of process knowledge and weak design links. The problem associated with the actual performance of the assembly system relates to re-utilisation issues.

As stated earlier, the only people that truly understand the assembly processes being carried out are the operators at shop-floor level. These people are rarely assisted in their maintenance tasks and the information they gather during the system operation are not documented at all. This creates longer system downtimes, due to the fact that they are not assisted in tracking the potential cause of the system failure, and re-occurrences of the problems: since the data collected in regards to the cause of the failure, and its recovery path, are not exploited in any way, these problems will be repeated. This is of great importance since anyone who has spent time in an industrial assembly system knows that a production halt may be due to machine failure, system design flaws, product design flaws, or even product component errors, such as inadequate choice of materials.

**NOTE:** system design is often carried out far from the shopfloor, by CAD specialists; this worsens the situation as these “experts” have little or no knowledge of the real everyday system performance aspects.

Since the source of a fatal production error can actually be due to a design flaw, operational information is of capital importance and should absolutely be fed back into the product lifecycle phases.

This brings the discussion to eco-sustainability issues, since the misuse of important information leads to a total lack of re-use of assembly equipment (this will be detailed in the next section). This is primarily due to the lack of process knowledge described earlier, but the operator knowledge, which is the only true source of assembly process knowledge, lies at the core of the problem. Basically, a better exploitation of the operators’ experience, with support measures for the maintenance aspects, would not only lead to enhanced process knowledge but far shorter production downtimes.

The advent of micro and nano-factories will obviously worsen this situation, mainly due to their extremely small size: human intervention in case of production failures will be impossible.

The risk that entire microfactories will be simply disposed of in case of fatal production failures is large. This, in time, will become an eco-sustainability issue.

The most interesting aspect in this discussion is that little attention has been brought to the fact that maintenance aspects may be integrated within the product design phase and control system applications. Once feedback from the production system is achieved, one may be able to forecast when machines, products and other items may need maintenance (preventive measure). If this is integrated within the product design phase and, subsequently, the system design phase, the user could be informed of upcoming maintenance aspects. This has been applied vehicles such as cars, where the driver is alerted by the control system that a service is due within xx kilometers. This philosophy could easily be applied wherever there is knowledge of the intervention required. Advanced control systems that monitor such aspects are technologically possible.

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Socio-Political Issues

Demography

Social factors that may come to have a major impact on our future technologies are demography, educational strategy, and economical stability.

The rapid decline in labour force and resulting narrowing of the skill base has been well defined [19] and constitutes a catalyst to the problem just defined. This may be considered a vital challenge for all sectors of the society in Europe. The alarming issue is the steady decline in births in Europe, which will inevitably lead to a lack of available workforces (see negative values for age groups 0-59, for OECD countries, Fig.2).

As a result, the industry will increasingly have to rely upon more extensive outsourcing or cost effective automation technologies.

Combined with product miniaturisation, this scenario clearly underlines the importance of developing new methods, standards and commercially applicable solutions for cost-effective precision assembly.

![Average annual growth rates](image)

The mechanisms for attaining successful sustainable production in Europe will also attempt to focus on well-selected scenarios. According to the Observatory of European SMEs [5], 93% of all employees in Europe operate within companies with less than 10 workers/employees, and over 120 million people are directly employed in the European SME sector (this value increases significantly if one adds the services around SMEs).

Being the real giants of the European economies, their particular needs will need to be highlighted. However, it must be noted that due to the fact that manufacturing is becoming ever more customised, and the product lifecycles continue to decrease, the underlying needs of manufacturing become identical for both small and large enterprise. The bottom line is that almost 31% of the workforce in Europe is currently employed in the manufacturing industry, which means roughly 34 million employees or 1550 million € in value adding activities.

The addition of the service sectors directly dependent on this manufacturing industry magnifies the figure significantly, and one is still not including the major European corporations! If the trend to let this business go out of Europe continues, Europe will have a serious problem in sustaining itself and its standard of living.

![WORLDWIDE population doubling time in years at current rate](image)

Europe’s demographical development in the coming decades is to be viewed as a critical factor. Prof. Zetterberg[9] points out a series of relevant factors:
Europeans were 27% of the world population in 1900, but are now only 12%. By 2100, Europeans will reach 7% of the global population.

Turkey will soon become the largest regional population outside Russia, outdistancing Germany, Italy and the United Kingdom.

Europe has the slowest population growth in the world. Basically, Europe is becoming a minority continent, with decreasing demographic power. At the same time, it has the most rapidly growing group of retired people. New services and products will be required, but where they will be developed and assembled if the working population is rapidly decreasing remains a major issue. The rapid decline in labour force and resulting narrowing of the skill base has been well defined and constitutes a catalyst to the problem just defined. This may be considered a vital challenge for all sectors of the society in Europe. The alarming issue is the steady decline in births in Europe, which will inevitably lead to a lack of available workforces.

As a result, the industry will increasingly have to rely upon more extensive outsourcing or cost effective automation technologies. As outsourcing poses serious long-term strategic threats, automation may become of vital importance.

In order to achieve this, major efforts in the improvement of work environments must be achieved.

Educational

By the early 1990’s, European R&D work in the field of Production Engineering had reached a peak, and several universities in Europe were actually awarded prestigious awards. Although successful at academic level, this work was not well adapted to the precise industrial requirements, primarily because the link between academia and industry was not so well established. At this point in time the economic recession hit Europe, which brought about a general lack of investment initiative for high-technology solutions for European production. The political focus, at national level, gradually moved to Information Technology (IT), telecom, and biotechnology R&D. The resources allocated to Production Engineering research have decreased ever since. When the telecom and internet business bubble finally burst, the problem of conquering new markets, with new products, and with totally new technologies become very evident. By this time, however, the production engineering research in Europe had been confined to a small set of very active, but widely dispersed groups in different universities. This is extremely alarming since new nations are entering the realm of high-technology status, with South Korea in clear focus and the Republic of China starting technological universities.

Furthermore, the next generation micro & nano-scale assembly technologies have quite different characteristics from the conventional and constitute a challenge to the conventional educational and training approaches. Biology, physics, and chemistry knowledge should be integrated within given courses.

As a result there is a need of a concerted effort in developing new academic courses and training initiatives based on closer cooperation between academia and industry.

The importance to enhance the public interest for Production Engineering activities is not entirely dictated by the need to increase R&D work in this field, but also to attract a greater segment of the available workforce to the industrial sector. Gender and ethical issues should also come be addressed in order to fully exploit the intellectual potential within the EU.

Venture Capital

The European Commission recently conducted a study of how venture capital trends differ between Europe and the United States, and went as far as to analyse how financing had changed since the early 1980’s. The study concludes that, on average, the profitability of the European venture capital industries is not fully meeting the risk-adjusted return requirements of the institutional investors (see fig. 5.0).

The figure also shows, quite clearly, that the USA has had an enormous head-start, with double and triple the values paid in capital, in the last 15 years. Venture funds have dramatically decreased by the turn of the century. The bottom line is that the business of the investee companies did not develop as predicted. This inability to commercialise innovation is a matter of concern, and does raise questions as to whether the commitment (or knowledge-see later) of management is sufficient. Europe, for instance, loses time and scientific grounds due to late exploitations: as an example, the IT expansion occurred in Europe too late, and the returns would have come after the “technology bubble” exploded. So the major conclusion may be that the conditions, knowledge and timing of capital investment may not be as good as required in Europe, and that we constantly lag in time. These facts were brought to light in discussions with industrial representatives in Europe. An interesting, even alarming, fact that surfaced was that the values indicated for European investments are usually not 100% accurate. Due to tax issues, the figures are usually manipulated. The reality is that Europe, due to the fact that there are no tax alleviations for R&D expenditures, is losing even more ground than what is officially given.
NOTE: the recent turmoil on the global stock markets has, and will have, a major impact on venture capital in the next few years. In an article by Claire Miller, it becomes obvious: "Even if salaries and bonuses hold up, carried interest distributions — the percentage of investment profits that partners receive — will likely fall."

The fact that the managers themselves will possibly gain from this brings us to the next two issues: management & ethics

According to the latest European Research Area Report:

The intensities of government and business funding of R&D have increased in a majority of Member States but remained almost unchanged at EU-27 level:

EU-27 is lagging behind the US, Japan and South Korea in terms of R&D intensity, mainly due to a lower level of R&D funded (and performed) by the business sector. The intensity of business funding of R&D has increased almost exclusively in Member States where this intensity was already low or very low. With the exception of Austria, EU Member States with medium and high levels of business funding have not been able to increase substantially their business R&D funding intensities. As a result, for EU-27, the intensity of business funding of R&D has declined slightly from 1.05 % of GDP in 2000 to 1.00 % of GDP in 2006. In the US, the decline was more marked, although from a much higher level.

Management

In the early 1900’s, the majority of manufacturing companies were created and driven by engineers. Philips, Electrolux (ex Zanussi), Ericsson, and most others are now major multi-national corporations, but their true wealth and technological basis was derived from a body of engineering-minded executives. As far as SMEs is concerned, the discussion is even more substantial. This has dramatically changed since the 1980’s, and a mainly economically knowledgeable community took over the leadership of most European companies. This, according to a large panel of experts, is undermining the long-term technological sustainability of companies due to the fact that management is not technologically well-versed, and thus fails to see the needs and benefits of more long-term strategies. Note that this has a major bearing on the inability to capitalise on innovation—see section Venture Capital! It is of some importance to clarify that most management structures in South East Asian companies still maintain a sound level of engineers at top-level management. As an example (see State-of-the-Art), the conclusions of an industrial case study on advanced control systems conducted at Daimler-Chrysler in 2001 concluded that, although the technology was extremely promising, it would probably fail due to the management’s lack of acceptance and/or understanding of its potential.

Summarising, one may find the following main issues:

- **quality of management issues**: short-term returns vs long-term success, management is causing problems due to career-minded moves or shareholder pressures, not technological issues. Once

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Unit C.3 – Economic Analysis and Monitoring of National Research Policies and the Lisbon Strategy

profits are attained, the bonuses go to the leadership, not the workers. In trying even illegal moves to promote short-term success (see ENRON, Parmalat, etc...), the outgoing management still receives pay-off bonuses whilst labour force gets fired.

- **Culture of management**: management needs more than knowledge of technology, it needs greater knowledge on how to manage engineering matters as well; i.e. how long does the exploitation of a given technology take, where/how do we begin, etc. Technology requires time to mature!
- **Self-rewarding management culture**: as above, but with the aggravating fact that long-term corporate strategy is no longer even thought of. Managers that attain mid-term improvements get rewarded, regardless of the fact that the company may be gone in 12 months time. Stock options are another example: middle and higher management may hold stock options. Their interest is to see a short-to-medium term rise in the share prices, after which they often change job and lose interest in the long-term results.
- There is an acute **lack of adequate business models** and supportive tools for technologically-oriented management (hence the need to develop adequate business tools).

Basiclly, our European societies currently denote inadequate values as they usually measure success on how quickly a company acquires wealth and not upon its long-term strategies. Obviously, this puts an undesired pressure upon management.

**Ethics**

Ethics is a broad subject and would actually need to treat many sub-topics. Areas of particular interest regard technology assessment, business ethics, environmental ethics and others. Due to the scope of this report, only a general review will be given. The conclusions drawn by the interviews pinpointed that business ethics seems to be posing greater challenges than expected. Business ethics are applied ethics, and refer to the rules, principles and codes of conduct that exist within a commercial context, and their effects extend to how the decisions taken at business level may come to affect the broader society. Three main ethical issues were raised:

- the ethics of internal reward schemes
- the ethical demands posed by globalisation
- sociological impacts

The first issue is not a surprise and may be better treated by a wider panel, but there are clear differences between the economist's view and the sociologists'. In recent times it has often been debated that **bonus schemes** for high-ranking corporate officials are necessary in order to attract the best candidates. This trend has escalated to disproportionate levels. In a society (European manufacturing) which is struggling to maintain its labour force quotas, these actions raise alarming questions. It also opens the door to an unjustified and potentially serious misrepresentation by the media, which could show how a single corporation outsources production to a low-wage nation, where the manual labour is performed by underpayed 16-17 year old school girls, whilst the management rewards itself for this move with a million-dollar bonus. As this actually occurs, the ethics should be seriously revised as to reflect the values and ambitions of an average EU citizen.

The second form of ethics is given by the globalisation trend, which actually has two dimensions: first of all, it refers to how globalisation itself is perceived and accepted worldwide. Secondly, it concerns how the technological innovation is viewed and implemented by different cultures, people, and religions: globalisation is multi-faceted. It should be noted that the inter-dependence of human societies at a global level, whilst sustaining actions at local level, is not a new phenomenon. It is the level and pace of this escalating inter-dependence that has caused turmoil, and the IT revolution has acted as a formidable catalyst. What is basically occurring is that many societies perceive the events as the forming of a "**global order**", which disturbs their own personal, or local views. For example, when sub-contractors or Contract manufacturers in low-wage nations take over production, there is little or no follow-up on their work environments and ecological approaches, which are often critically poor. Child labour, unprotected workers, and dumping of waste are a few common examples (http://www.csmonitor.com/2006/1222/p01s03-wosc.html, http://www.american.edu/TED/hongkong.htm).

Summarising, it seems that one needs to better understand the interdependence of ethics and successful business as this used to be a trade mark of past success in Europe.

**EU Growth**

Europe is predominantly driven by SMEs, which generally have limited financial and technological muscle, therefore one may conclude that any solution that favours their conditions is to be preferred. The figure

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7 “Major controversy breaks out over top pay”; European industrial relations observatory; http://www.eiro.eurofound.eu.int/2003/05/feature/n0305102f.html
8 “The ethics of globalization”; Dwight H. Terry Lectures, by Singer at Yale University in Nov. 2000
below clearly illustrates that Manufacturing remains a major socio-economic force in European terms, and that disregarding its needs would be catastrophic.

![Value Added](image1)

![Jobs](image2)

**Figure 2.0- Job Levels and Value Added to Europe through Manufacturing [5]**

According to the Observatory of European SMEs [18], over 120 million people are directly employed in the European SME sector. Being the real giants of the European economies, their particular needs will need to be highlighted. Note that SMEs are usually suppliers and sub-suppliers to the larger companies, and that their competitiveness is fundamental for Europe.

The bottom line is that almost 31% of the workforce in Europe is currently employed in the manufacturing industry, which means roughly 34 million employees or 1550 billion € in value adding activities. However, it must be noted that due to the fact that manufacturing is becoming ever more customised, and the product lifecycles continue to decrease, the underlying needs of manufacturing become identical for both small and large enterprises. The fact remains that assembly & manufacturing solutions that may allow the end-user to automate their operations at their own rate, with high reliability, and requiring minimal setup times are still practically impossible to find.

Production follows markets, and develops markets. This means that it is extremely important to maintain production in Europe. The annual growth in electronics production in China is estimated to be approximately 15% for the period 2001-2008 and in Europe of not more than 4%. Major efforts are therefore needed to reverse this trend. Albeit the absence of adequate automation solutions, the market for robot handling systems is forecasted to have an average annual growth of 5.3%. The report also states that this market is predicted to experience high growth in revenues, especially if advances are made in software and its compatibility with modular-type equipment.

**Resources**

Natural and energy-producing resources will become the major player in world politics. The oil requirements of the USA are now mainly imported as its own production meets only 25% of the demand. Water consumption has reached such levels that the Colorado River is decreasing in level each year. The Chinese and Indian economic boom has increased oil consumption to such levels that we can no longer expect this resource to remain available much longer. Details are shown in the figure below.

Note that the remaining oil reserves may now be difficult to exploit as it becomes more and more difficult to extract the little that is left ("tooth-paste tube problem"). As given by Worldwatch:

**The long-term future of oil companies may not be so bright, however. ExxonMobil reported a decline in oil and natural gas production in 2007, and many companies are finding it hard to replace their reserves.**

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only have the largest oil fields already been developed, most of the promising prospect areas are controlled by state-owned oil companies, which hold 80 percent of the world’s proven oil reserves.10

The other key resource remains water. The Watergap2.0 report clearly reports that the USA, China and Australian usage is well beyond the renewable levels, creating severe water stress issues (see map below).

One of the many serious conclusion drawn by this report states: “One question that arises is whether water scarcity will inhibit industrial development...especially in developing countries, industries will have to rigorously compete with household and agricultural water users for the few water resources remaining. Industries will either win this competition, or adapt to a far lower usage of water.” (Source: http://www.usf.uni-kassel.de/usf/archiv/dokumente/kwws/kwws.2.pdf)

10 Oil Consumption Continues Slow Growth, by Joe Monfort | March 26, 2008, worldwatch institute
Policies

The EC is constantly monitoring the ecological impact of new and old technologies, and also observes how these influence economy, society, globalisation and trade agreements. The positive aspect is that the EC has mechanisms to stipulate and enforce standardisation and regulations, which are beneficial to industry. However, it is also true that most European companies are compelled to abide to these supposedly correct and ethically just regulations, whilst competing nations in emerging markets and others are not. This is an unbalanced approach, and it does stretch to all sectors of industry. In the long-term these regulations may bring new services, improved environments, and better control of new technological impacts. In the short-term they may cause the fall of many European companies. An example of the impact of political decisions on an industry are clearly given by the nuclear debate in Europe. Many EC nations have stopped their nuclear reactors after national referendums. Many of these nations are now purchasing electricity from other nations, often from nuclear-powered plants but also from coal-driven powerplants. The fact remains that ecology will continue to influence our societies and everyday lives. This produces media attention and, more often than not, emotional social reactions rather than factual responses. This influences politicians greatly and leads to, at times, destructive decisions. However, we forget that we live in industrial societies that are ever more fragile and that their erosion will cause major social disruptions. Greater care needs to be taken in assessing the risks being underlined by ecologists [17] as many have failed to materialise:

- In the early 1980's, reports indicated that forests would be decimated within years. Satellite pictures (NASA) reveal that by 1999 the woodland area on earth had increased by 6%.\textsuperscript{11}
- Ecologists in the mid-1980s had stated that the sea level of the Mediterranean would have risen by several meters within decades. It has, since then, receded.
- We are mounting huge campaigns against genetically-modified seeds whilst they may actually provide salvation for Africa (drought-resistance) and offer alternatives to pesticides.

Whatever the particular study, it becomes obvious that less political pressure and greater long-term knowledge needs to be gathered to correctly asses the pros and cons of the changes we are to face. In this equation it is also vital to asses the impact the ensuing regulations will have on the EC manufacturing industry, and how we may be affecting their competitiveness. If this is not carried out in a balanced and righteous manner, the dumping of toxic substances on African shores may only increase, and the real issue of ecology is only shifted to other nations.

Summary

The main question that society has to ask itself is whether the EC is responding to the challenges with an adequate financing of the R&D sector. Basically, are we up to the challenges set by the Lisbon Treaty and our global competitors?

The major reports written by the European Research Area (Science Technology and Competitiveness, key Figures 2008-2009), clearly denotes that the effort is still lagging behind Japan, USA, and South Korea. Furthermore, China’s efforts are now practically equal to Europe’s. The figure below (courtesy of ERA) depicts this quite well:

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\textsuperscript{11} "Le Bugie degli Ambientalisti"; R.Cascioli, A.Gaspari;PIEMME, Edited by T.Regge; ISBN 88-384-8376-0
One of the key reasons behind the EC’s lack in funding resides in the decrease in private/corporate funding for R&D in the past years. The same report goes on to cite the following:

"R&D funding by business in EU-27 is at the same level as in China, and substantially lower than in the US, Japan and South Korea:

In EU-27, R&D financed by business enterprise as a % of GDP decreased by 5 % between 2000 and 2005. The EU-27 value of 1 % in 2005 represented 38 %, 41 % and 59 % of the corresponding values for Japan, South Korea and the US respectively. If business R&D funding from the ‘abroad’ source of funds is added to R&D financed by business enterprise, the conclusion does not change drastically [23]: the difference in total R&D intensity between the EU and the US, Japan and South Korea is almost exclusively due to the difference in the level of private funding of R&D."

With regards to its oldest industrial counterpart, the USA, the findings of this report are quite clear:

"The US has both a larger and more research-intensive high-tech industry than the EU – these are the underlying reasons for the R&D gap between the EU and the US in manufacturing industry."

In face of these conclusions, based on what is probably the most in-depth analysis of the European Research Area, it becomes painfully clear that the EC manufacturing industry must enhance its technological level, increase its R&D budgets, and begin to take the challenges posed as future opportunities.

As shown below, the particular topic covered in this report, the Manufacturing Sector, is one of the least priorities in the EC currently, whilst almost the rest of the world perceives it as a major R&D sector.
Emerging Products/Industries

The global scenario has, up to this point, depicted a set of both constraining and motivating conditions that may come to determine the type and scope of technologies that may appear in the near future. On the other spectrum, and at a much finer scale, there are some technologies and products that have already presented themselves as potential breakthroughs, and which will need to be briefly detailed. This section will delve with these aspects only lightly, as they have been subject of greater scrutiny in earlier roadmaps (µSapient[22], MINAM Roadmaps,[23]). Furthermore, it is the manufacturing aspects that these technologies and products may come to require that are of greater interest within the EUPASS context, and this perspective will be subject of the summary.

A well-highlighted (µSapient Roadmap,[22]) trend is the increasing level of micro-components and internet-based services within products, which range from insulin pumps to inhalators. This is not a temporary trend since future products will require even more miniaturised assemblies, as some nanorobotic applications forecast, and real-time services will abound. The characteristics of most of these products do not differ greatly from those of the telecom industry, where customer-tailored variants with ever-increasing functionality are becoming a necessity. According to Prof. Kleinkes (IWAM, Dortmund[24]), there are 200 companies worldwide providing 35 nanomedical products from bandages with anti-microbial silver nanoparticles to pregnancy self-tests with colloidal gold12. In this study, the worldwide market is estimated at US$6 billion. More than 150 pharmaceutical and medical products employing nanotechnology are emerging. The analysis shows that:

- 54% of those companies with nanomedical activities are developing drug delivery systems
- 24% of those companies are developing diagnostics such as nanoparticles for molecular imaging
- 19% are working with orthopaedic products.

Such new product categories may include:

- medical devices that monitor hormone levels on a real-time basis AND dispense adequate medication continuously.
- smart connectors that enable either multiple device connection OR enable connectors to monitor certain maintenance aspects.
- smart test tubes and other collecting devices that reduce paperwork and self-monitor.

Figure 10.0- Continuous Glucose Monitoring within an Insulin Pump (Courtesy of Medtronic)

Figure 11.0- Smart Connectors
New assembly needs have also been denoted in conventionally-sized product markets, such as the biomedical and pharmaceutical industries. The applications range widely, from packaging to initiating surgical adhesive swabs (see below).

These industries are reluctant to outsource on the basis that quality (zero-defect production a common FDA requirement) and design are of vital importance to their survival. This alone demands that outsourced production maintain an as high level of quality as the present, which in their opinion is not possible. Another factor is that they have pinpointed that the importance of design decreases when production is outsourced, which is not acceptable since this leads to a less competitive product. Typical trends denoted by these industries include:

- Services are a growing need: customer knowledge, availability, supplier relationship, etc.
- High-variant assembly (increasing) with relatively long life-cycles.
- Modules, need for adaptable assembly equipment is increasing.
- The product identity is required to be finalised at the latest possible stage.
- Integration of certain manufacturing operations is becoming essential.
- Increased levels of on-board product services (intelligent devices).
- Increasing need to have high process traceability.

This industry has been dominated by the packaging system suppliers, and this phase of production remains dominant. Recent developments, however, would like the packaging to become more digitally-oriented, such that variants can be determined on-the-fly. This is what they term as 3D Digital Packaging.

**New Biomedical Production Branches:**

*Stem-cell manufacturing plants:* these may come to represent an entirely new branch of assembly, demanding extremely clean room assembly cells for the construction of human tissue and/or specific cells. These may not always require extreme precision but must be easily reconfigurable and definitely adaptable to varying demands and constraints.

*Zero-assembly cells:* these are operations which do not require classical assembly/joining operations, such as Free-Form Fabrication, laser applications, etc. That is, material is added without manipulation of the workpiece/base product. Note: these should be considered as an integral part of an assembly system even if they do not require classical joining/assembly. As integration of components is one of the major problem areas, the topic should not be handled separately.

- *"Target-killers":* micro-machines that attack only cancer/diseased cells. These products exist but are impossible to produce in vast numbers, including micro-robots\(^\text{13}\) that contain radioactive capsules that can find and kill only cancer cells. Wireless capsule endoscopy, which is a serious R&D topic in the USA and Japan, is amongst these products. Zero-defect production and precision are problems within the medical/pharmaceutical/space industries.

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\(^{13}\) *Flagellar Swimming for Medical Micro Robots: Theory, Experiments and Application; Gábor Kósa, Péter Jakab, Nobuhiko Hata, Ferenc Jólesz, Zipi Neubach, Moshe Shoham, Menashe, Zaaroor and Gábor Székely*
• **Stem-cell manufacturing plants:** extremely clean room assembly cells for the construction of human tissue and/or specific cells. Do not require extreme precision but must be easily re-configurable. Example: from InPharmaTechnologist.com, By Gareth Macdonald, 10-Jul-2008 - *Vitro Diagnostics has opened a new facility for the development and manufacture of stem cell products for commercial application in the pharmaceutical industry.* The plant, which is located in the Coors Technology Center in Golden Colorado, is fully compliant with US Food and Drug Administration (FDA) regulations covering the manufacture of human stem cell products. It will be used for the production of stem-cells for use in medical research, drug production and discovery, including cell therapy for diabetes.

• **Multi-variant pill production:** high volume production of common drugs in a variety of brands, packaging, and dosage ranges. Mainly to cut costs of production and keep quality control all within one system.

To underline the level of future competition, here are a few examples (taken from InPharmaTechnologist.com):

**Indian government acts to promote biotech**
By Nick Taylor, 09-Dec-2008

*India's industry has been boosted by news that 20 more biotech parks are to be set up and financial actions are being implemented to help small businesses.*

The biotech parks are being set up to promote life science research, with the Indian government hoping to see scientists develop treatments for diseases that are a "burden for the poor". India currently has four biotech parks, with construction of an additional 20 expected to significantly increase research capacity.

To ensure the new facilities are staffed by "high quality human resource" a 10-year agreement has been signed between the Indian Department of Biotechnology and the Wellcome Trust, which funds biomedical research around the world. Details of the deal have not been published.

**Taiwan’s biotech statute continues to attract global players**
By Gareth Macdonald, 29-Oct-2008

*Taiwan’s efforts to position itself as a major biotechnology hub received a further boost today with the opening of Merck KGaA’s dedicated technology training centre in Xizhi City, Taipei County.*
The Asian Technology Training Center (ATTC) will help local customers that use Merck's range of chromatography solutions for the production of biologic drugs and is a reflection of the development of Taiwan's bioprocessing infrastructure.

In the 1980s the Taiwanese government began to invest in biotechnology R&D, spending around 30 per cent of its annual science budget on the sector which was, at the time, still relatively small. This investment resulted in the development of three science bases: Hsinchu; the Central Taiwan Science Park and the Southern Taiwan Science Park, where Merck's new unit will be based. The three science parks alone generated revenues of $60.8bn last year according to Taiwan's National Science Council (NSC).

This infrastructure has proved irresistible to industry players like Applied Biosystems, Invitrogen, Dionex and Novartis which, in addition to Merck, have all established a presence in the country. However, rather than rest on its laurels, in 2007 Taiwan redoubled its efforts and issued a "statute for the development of biotechnology new drug industry" containing a raft of measures to further encourage both international and local biotechnology companies.

Key features of the legislation included a 35 per cent tax break on R&D spending for biotech companies and the insistence by health authorities that all manufacturers comply with inspection rules set out by the European Union.

EU cash for plant cell biosynthesis
By Nick Taylor, 24-Sep-2008

The production of pharmaceutical products in plant cells has been given a boost, after the European Union ploughed $8.8m into a research programme.

Funding was awarded to the SmartCell project, which aims to manipulate plant cells to produce commercially viable yields of pharmacologically active secondary metabolites.

VTT Technical Research Centre is coordinating the project, which is a collaboration between 14 leading European research institutes and five enterprises of varying sizes.

Kirsi-Marja Oksman-Caldentey, project coordinator and chief research scientist at VTT, said: “The opportunities offered by plant biotechnology could be much more extensively exploited in the pharmaceutical industry.

"The latest research methods can be used to intensify the production of valuable agents in plant cells; in a manner of speaking, plant cells could become real 'green factories’." Plants produce a wide range of secondary metabolites, some of which have been found to be pharmacologically active. However, these compounds are generally produced in very small amounts over a long period of time, making commercially viable extraction difficult.

The research aims to manipulate a plant cell’s secondary metabolite synthesis pathway to produce sufficient yield of a pharmacologically active compound. Initial research will focus on the synthesis of terpenes, which are produced by a wide variety of plants.

Terpenes were selected as their production showed promise in preliminary tests and because paclitaxel, a member of the same chemical family, is partially produced from plant cell cultures. Derivatives of terpenes include steroids, menthol, camphor and cannabinoids.

Similar manipulations have already been performed on microbes but the pathways within plant cells are considerably more complex. The exact mechanisms used to synthesise small-molecular-weight compounds are not well understood, which poses difficulties for those trying to harness the pathways.

By bringing together researchers from fields including plant science, fermentation technology and biochemistry, the project hopes to gain a more complete understanding of secondary metabolite synthesis.

The intention is for institutions participating in the research to be given priority use of tools developed by the programme, but the technologies will also be made publicly available.

Work on the project is due to commence in January 2009 and run for four years, with a total budget of $12.5m.
**EUPASS Short Survey.**

EUPASS carried out a short survey amongst its members in order to achieve a better comprehension of the issues related with the new and fashionable concept of the “Adaptability”. The results are listed below and refer to the “Evolvability-Adaptability Paradigm” which has been developed inside the EUPASS environment. The questionnaire is based on Likert scales: each question is followed by a series of items evaluable by the relative personal vision of the reader.

**Question 1:** Which is the importance of the following **Drivers** for the introduction of the Adaptability in the current assembly field?

![Chart showing the importance of various drivers](chart1.png)

The group is quite heterogenous, but in the end everyone basically agrees that the development of Process Oriented Approaches seem to be perceived as the key to attaining Adaptable Assembly Systems. Other important drivers appear to be Future Technologies, Cost issues Design and Integration.

**Question 2:** Which is the importance of the following **Barriers** for the introduction of Adaptability in the current assembly field?

![Chart showing the importance of various barriers](chart2.png)

Outsourcing is considered the most significative barrier to the introduction of the Adaptability Paradigm. As detailed in the previous chapters of this roadmap, companies today are focused on the short term, and very often assembly is not considered a strategic process that deserves to be included in the “core competences”. This enables outsourcing and the subsequent loss of product process knowledge. Other possible obstacles for a quick diffusion of the new view is the poor knowledge and standardization of the assembly process in general (especially if compared with other manufacturing processes), and the resistance to change from traditional approaches.
**Question 3:** Which is the importance of the following **Technical Requirements** for the introduction of the Adaptability in the current assembly field?

![Graph showing importance of technical requirements](image)

Table 3

This graph shows what EUPASS members feel is the future challenge for the correct development of the Paradigm. On one hand, *Modularity* and *Distributed Control* are the bases, on the other hand the *design phase* should account of the assembly needs such as already done for the manufacturing needs. In reality, as all of the above issues are important ingredients in Adaptability, the balanced reaction to the question is logical.

**Question 4:** What is in your opinion, is the **Market Sector** that will probably drive adaptability demands forward?

![Graph showing market sectors](image)

Table 4

The response to this question clearly shows that high-volume, low-variant production is definitely not the targeted market sector. Most EUPASS members understand very well that the Adaptability Paradigm is more suitable for the lower volume productions, with high variant numbers and decreasing size of products.

The Survey clearly points out that micro production of products in many variants, of which each variant may be in small volumes, is the critical area for assembly automation. This segment cannot be handled manually. However, even large complex products that exist in many variants also fall among the critical areas due to the need to maintain process knowledge in-house.
**Consequences**

Recent Roadmapping efforts (µSapien\[22\], MINAM\[23\], ManuFuture [25], etc.) clearly indicate that micro-assembly will increase, as well as the need for MEMS and micro-devices. Other, more traditional branches may have to regain a new dimension, such as the automotive and fashion sectors. The bottom line is that assembly will remain a major manufacturing sector, and that micro-assembly does not often exist as an isolated process for any given product. Therefore, the efforts for future assembly need to be more general and directed at global product goals rather than sectorial ones.

As stated earlier, assembly is now a global market. Outsourcing cannot be considered an evil but an integral part of a successful company strategy: local assembly capacity may be the only means of penetrating global markets, so local production facilities will continue to exist and expand. The real issue is HOW to outsource, and on the basis of which ruling European regulations.

Therefore, the big questions for Europe are: where and how will these new products be manufactured and assembled?

The assembly location is strictly bound to market and company strategies. However, it is very common to see final assembly be re-located, without any thought being given to the core competency being given away for free: some final assemblies are innovative company processes! Therefore, it is far more important to assess which product manufacturing processes are strategically vital to the company, and then exploit this knowledge accordingly. The correct outsourcing of non-strategic or labour-intensive processes is more adequate. Cheap labour is no longer a justifiable reason for outsourcing as few companies have product ranges that require manual labour to an extent that may justify strategies based on labour cost reduction alone. The issues reported in the Global Scenario should clarify this. The US National Academy of Sciences points out similar problems in one of its early studies [26]:

- Management needs to understand the technology behind its products and processes far better, and acquire the knowledge to use it.
- Core competitive capabilities should include the combination of technologies, skills and products.
- The commercialisation of new technologies is highly dependent on the integration of product and process design & engineering.

However, the goal of acquiring a management group that understands and applies these qualities may still be refrained by a set of rarely highlighted factors. These may be summed up as:

- The funding for new technologies needs to be focussed on well selected criteria and not on “fashionable” trends. Industry needs to be listened to more carefully by European funding organisations, and reports from industrial institutions taken far more seriously (i.e.-ManuFuture).
- The funding and investments need to be given incentives, either through tax regulations or national/international initiatives.
- Non-traditional topics need to be integrated within Production Engineering curricula as the manufacturing technologies become more integrated with the products, supply chains, and processes.

The first two points above need to be tackled by the European Commission and industry. The other active parties (industry & academia) may, for the time being, only continue to highlight the urgency of these aspects and train their management to better understand the technological issues behind their products (and avoid short-term decision making incentives!). For the third point, however, it is urgent to understand that Adaptive Assembly Systems will only become a reality if the products and assembly processes are dynamically linked in their development phases. This is well understood by industry, as the EUPASS survey pointed out- see Table1. This issue relates directly to the possibility of better exploiting innovative company processes, maintaining them in-house, all the while attaining fast and high-quality production.
EUPASS – OUTLOOK REPORT

MAPPING THE NEEDS

State-of-Art vs Opportunities/Threats

Evolvable, sustainable assembly R&D is aiming to improve the agility, maintainability, and rapid deployment of precision assembly systems in Europe. These characteristics do, however, need clarification.

Relating back to the ability to rapidly plug and interchange modules, several things which are vital for the success of Adaptable/Evolvable Systems emerge from the list of module constraints.

1. First of all, the mechanical development of the modules is a phase which actually occurs OUTSIDE the system functionality: the modules need to be completed and ready to use prior to any installation. Their development is always carried out in parallel and/or behind the scenes of the actual production cycles!
2. All the aspects that relate to integration of modules and/or systems are far more vital to rapid deployment than mechanical developments.
3. Interfaces, emplacements, protocol standards and other advanced interfacing standards need to be agreed upon, developed and certified as compatible.
4. An innovative control strategy that minimises integration delays is critically important, including the need to minimise if not eliminate codification (programming).

Granularity refers to the level of modularity that may be attained by any given system. The finer the granularity, the greater the potential for adaptability, as this is very closely linked to evolutionary principles: small-entities evolve quicker as there are fewer domains to be accounted for. However, this is strongly related to the above issues, as evolvable systems need to continuously monitor and exploit information regarding their environment. Finely granular systems could benefit in this domain since their "communities" are more restricted and can, therefore be confined more easily. If one then couples this attribute to that of rapid deployment, things become more demanding: rapid deployment is basically the quick dispatching, integration and setting up of modules into a fully functional assembly system.

Deployment, as proven in the literature [39, 40, 41], is primarily an integration issue:

![Figure 56- Time Scales to System Deployment](image)

In rough terms, one may state that system or module deployments consist of (in time/cost terms):
- physical installation: 5-10% (pre-planned by software tool)
- electr./digital plugability: 5% (simply connecting cables, USBs, SMEMAs, etc.)
- system integration: 85-90% (control, etc; synchronising, up to >90% throughput)

As known to most assembly system installers, putting a system together mechanically should be a simpler task than getting it actually running and up to a minimum of 90% throughput. All the "finetuning", debugging, and other issues require an infinite amount of time and are absolutely related to the integration issues. Therefore, the "adaptability" dimension stretches to how quickly the system components may set themselves up autonomously: self-configuration becomes vital to adaptable, rapidly deployable systems.

Therefore, if Europe intends to attain a such solutions, the integration phase needs to be a major priority. Decentralised control, self-configuring assembly system components, and re-usability become crucial R&D topics.
NOTE: reconfiguration of systems is, basically, re-integration! If we fail with integration, reconfigurations become even more demanding!
Hence, it is hereby deemed important that modular, rapidly deployable production system solutions adopt moderate emergence with “intelligent” modules exhibiting social behaviour.

**GAP 1:**
Re-assert a scientifically valid European vision for its Automation Sector - define a referential architecture that may set the conditions for a quantifiable validation of the fundamental requirements.

**GAP 2:**
Focus on the basic essentials of a successful modular, evolvable, open-architecture for Assembly Automation: interfaces, standards, and control approaches. Mechanical developments are only to emerge out of the strict Control solutions' constraints!

**GAP 3:**
Re-assert the validity of scientific innovations that may support adaptability, evolvability and fault-tolerance. Emergent behaviour, multi-agent architectures, and complex systems theory should be highlighted.

**GAP 4:**
As with the results of roadmapping efforts done in 2003, the formalisation of assembly processes is still greatly overdue. Without this work no concrete, applicable solutions may be derived.
Enabling Control Aspects

The big question then becomes "how does one attain true adaptability" within assembly systems. Therefore, main issue being addressed in this section describes the new R&D areas which will become predominant in the quest for true adaptability. The main topic is, and has been, evident for a number of years: clever mechanical solutions alone will not suffice, dynamic adaptability depends most heavily on novel control solutions.

Numerous scientific domains investigating phenomena which EAS also exhibit have emerged in the last few years, which can provide helpful tools and valuable theoretical background to cope with the complexity of manufacturing systems.

Adaptability

In the late eighties and early nineties, the general trend in precision assembly was to develop Flexible Assembly Systems (FAS) and Flexible Automatic Assembly (FAA) cells. The goal was to have general flexibility, but the actual assembly processes were not studied in depth, therefore resulting in unstable / non-robust or badly adapted solutions. They were fairly adequate to many different product types, but failed to be very performing in any domain. The high cost of such installations (integration) was another heavy problem, especially for smaller companies. Flexibility, instead of the actual assembly process, has been the core issue of most of these developments. As shown in the figure below, the lower a component is positioned in the hierarchical structure, the more flexibility is necessary to ensure a certain flexibility to the whole system: the "rate" of adaptability/evolution needs to be higher at the lower levels if one is to achieve adaptive systems with inherent complexity!

This means that even a system with low adaptability needs a very adaptive control: this may imply that FAA solutions also failed because they never provided flexible/agile control systems!

The next attempt at finding a solution was Re-configurable Assembly Systems (RAS- see Fig.15.0). In RMS, the Assembly System design starts from the "New Product Requirements". The product to be assembled is analysed in order to find all the "Assembly System Requirements", which means that the driver of the whole process is the Product. In such an approach there are no links between the Product Design process and the successive steps: it leaves the maximum freedom to the designers, but this is not always the right strategy for the company success.

Basically, the real objectives should not have been flexibility or reconfigurability. These are characteristics, not objectives. The real objective is system adaptability, which targets the following four points:

1. Optimised functionality: the assembly equipment is kept as simple as possible by deriving small, dedicated, process-oriented modules. These may be interconnected to form cells or systems.
2. Optimised orchestration: the control system needs to be the most agile aspects. This is achieved by adopting a multi-agent based, distributed control approach with embedded controllers.
3. Adaptability: the modularity allows for stepwise upgradeability and economic flexibility (it is cheaper & simpler to change a module than modify a system). The actual system may also adapt to minor changes via its control system, which, being skill-based, allows for emergent behaviour to be exploited.
4. Robustness: the equipment is dedicated, small, and includes an own processor. Some modules (robots) may even be reconfigurable. The control system is goal-oriented, and the system is process-oriented. This results in a dedicated system based on an adaptable concept with advanced interfaces.
Fundamentally, what is required is an approach that suggests that true agility/flexibility can only be achieved if the lowest building blocks of a system are those that exhibit the highest rate of adaptability/evolvability. As the clustering of components increases in complexity, so does the agility/flexibility decrease. Hence, in order to build truly agile systems, one must begin by considering the control architecture.

**Future Control Issues**

To properly solve the requirements needed for future adatable assembly systems, it is fundamental to develop biologically inspired solutions that use principles from biology, complexity theory, swarm intelligence, chaos theory, self-organisation and emergence. Coping with emergent behaviour will be fundamental, and taking profit of emergent capabilities will open considerable potential for new solutions.

This section will detail some underlying concepts, and detail the main actors, which will influence future control solutions for the manufacturing industry.

**Complexity Theory**

Complexity Theory looks for simple causes leading to complex behaviors (Delic et al., 2006[28]). Complex systems are spatially and/or temporally extended non-linear systems with many strongly-coupled degrees of freedom. They are composed of numerous in themselves often simple elements and are characterized by collective properties. EAS consist of numerous equipment modules which are connected to each other and have multi-lateral interactions. Each of them has some degrees of freedom, which are constraint by other system parts. Together, the modules form a system with the desired global behavior.

Chaos Theory is often considered as a part of Complexity Theory, focusing on nonlinear aperiodic dynamics, where the phenomenon of chaos stands for the cases when future outcomes are arbitrarily sensitive to tiny changes in present conditions (Gell-Mann, 1995[29]). Manufacturing systems often exhibit sensitivity to specific conditions and to disturbances. Certain factors lead to system breakdown while others have no significant effect.

**Artificial Life**

Taking natural life and its characteristics as an example, scientists attempt to create life-like behaviors with the capability of evolution on computers and other “artificial” media. EAS are very similar to artificial living systems. They have a modifiable structure, will exhibit some kind of self-organization, can adapt to their environment, and react to stimuli. They are capable of evolving according to the circumstances, namely in terms of equipment states, and can incorporate newly available technology. As any living organism, they will include efforts to keep themselves in a constant well-functioning state through self-surveillance and self-management – at least to a certain degree.

The dynamics of swarm-building living organisms as well as the application of the concepts to Artificial Life are studied within the scope of Swarm Theory. Indirect ways of communication, namely stigmergy, have been learned from ant societies: information in the form of volatile pheromones is deposited in the environment and thus reduces or avoids direct communication between too many peers. Mechanisms similar to those found in fish shoals and bird flocks can be used by mobile robots for coordination with their fellows. The robots’ autonomy and their capacity of collaboration are fundamental. Being reactive and proactive devices, they often include reasoning capabilities.

Agentified modules in EAS can be seen like the members of a swarm where coordination can be based on similar strategies. Even if their mechanical properties are diverse, from a software point of view they have similar or identical characteristics. They can participate or withdraw from a swarm without disturbing the others, and thus permitting true and immediate Plug & Produce functionality.

**Autonomic Computing**

Although at another level than the other areas described above, Autonomic Computing is a fundamental concept for EPS. The vision of Autonomic Computing (Kephart et al., 2003[30]) refers to the tendency of computers to become ubiquitous. Forming large networks and having complex and multiple interactions, they
Agent Technology

Because the approach towards a fully biologically inspired solution and, in particular, the issue of self-organisation and emergence is difficult, a stepwise approach needs to be devised in developing future control solutions. Therefore, current strong R&D approaches are all using methodologies in which the different constituents of the system are considered as modules with intelligence. This means that every manufacturing component at different levels of granularity (from entire workstations to unit or components such as grippers or even sensors) are considered as intelligent entities (with computational power).

General purpose modeling paradigms such as Multi-Agent Systems (MAS) and Service-Oriented Architectures (SOA) currently align as the probable vehicles for embedding the conceptual frameworks hereby briefed on a ground of their own, as they by default support the features earlier detailed and additionally assure overall interoperability and integration in heterogeneous environments. They will also be the natural candidates to support self-organizing and emergence concepts highlighted above.

More than distributed platforms or technologies, SOA and MAS provide fundamentally new general purpose modeling metaphors. Rather than understanding MAS and SOA as competing paradigms, profiting from the best of both worlds presents a step further in modeling, designing and implementing self-properties to maximize robustness and performance of distributed assembly systems.

Service Oriented Architectures (SOA)

SOA’s basic building block is the service abstraction. The definition of SOA is far from being agreed as a search in the literature easily confirms. Contact points between the numerous definitions frequently include the following topics:

- Autonomy: there are no direct dependencies between the services.
- Interoperability: is specified at interface level omitting unnecessary details.
- Platform Independence: the services are described using interoperable XML-based formats.
- Encapsulation: services provide self-contained functionalities that are exposed by user defined interfaces
- Availability/Discovery: the services are published in public registries and made available for general use.

As a growing modeling paradigm for distributed systems, SOA is often confused with a wide range of networked information technologies. In this context, Web Services are the preferred mechanism for SOA implementation.

The Web Services Working group of the World Wide Web Consortium (W3C) defines Web Service as: “a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically WSDL). Other systems interact with the Web Service in a manner prescribed by its description using SOAP messages, typically conveyed using HTTP with an XML serialization in conjunction with other Web-related standards.”

Although a significant share of the research in SOA focus on modeling and supporting inter enterprise relationships, there is a favorable convergence of factors that are rendering it attractive in the establishment of networks of devices namely: the availability of affordable and high performance embedded devices, the expansion and low cost of Ethernet based networks and its acceptance in the industrial domain, the ubiquitous nature of the Internet, the existence of lightweight, platform agnostic communication infrastructures, etc.

This has triggered several European projects in the field including industry’s heavy weights. These have created a Service Infrastructure for Real time Embedded Networked Applications; Devices Profile for Web Services (DPWS), DPWS-based SOA for automation systems, and service oriented diagnosis on distributed manufacturing systems.

The Devices Profile for Web Services (http://schemas.xmlsoap.org/ws/2006/02/devprof/), whose initial publication dates from May 2004, defines the minimal Web Service’s implementation requirements for: secure message exchange, dynamic discovery, description and subscribing and eventing. DPWS specifically targets peripheral-class and consumer electronics-class hardware guaranteeing compliance without constraining richer implementations.

Multiagent Systems (MAS)

Most definitions for agents are of functional nature and relate to their authors’ background and the systems under study. Nevertheless, it is possible to isolate a common set of characteristics widely accepted:

- Autonomy – agents act individually fulfilling their individual goals.
• Sociability – agents interact among each other establishing an intelligent society.
• Rationality – an agent can reason about the data it receives in order to find the best solution to achieve its goal.
• Reactivity – an agent can react upon changes in the environment.
• Proactivity – a proactive agent has some control on its reactions basing them on its own agenda and objectives.
• Adaptability – an agent is capable of learning and changing its behaviour when a better solution is discovered.

A Multiagent System (MAS) is, in this context, a composition of several agents, each having incomplete information on a particular problem, communicating and cooperating, in a decentralized and asynchronous manner, in order to solve it. MAS results are broader than the sum of individual contributions. As stated earlier, emergent industrial paradigms are: modular, decentralized, changeable and complex. A multiagent system is by nature a decentralized and modular (and thus, easily changeable) environment, able to solve complex problems.

Pilot experiments have occurred in industrial setups there are, however, open challenges. Most development platforms target local area networks and implement centralized agent management systems that constitute both a bottleneck and centralized node of failure.

Furthermore most agent development environments are still heavy from a computational point of view with significant memory footprints and lack operational support for real-time environments.

**Merging MAS and SOA**

At a glance, both paradigms support the idea of distributed autonomous entities and provide an effective modeling metaphor for complexity encapsulation. Nevertheless SOA emphasizes contract-based descriptions of the hosted services and does not provide a reference programming model. MAS, on the other hand, support well established methods to describe the behaviour of an agent. Automation environments are typically heterogeneous and the lack of a structured development model/template may render system designing, implementation and debugging harder. Furthermore agents are regulated by internal or environmental rules that dictate social behavior and support, to some extent, flexibility and adaptability to changes in the environment. This is of major importance when considering systems that undergo dynamic runtime changes which is the case of the production paradigms earlier referred. SOA are typically supported by widely used web technologies and assure interoperability with a wide range of systems easily spawning over the internet. Most well-known MAS platforms are optimized for LAN use and are restricted to compliance with well defined but less used interoperability standards. Additionally, recent frameworks like DPWS provide high performance Web Service support for devices, with limited resources, without constraining services implementation. Most MAS platforms are computationally expensive.

There are numerous successful experiences with agent-based systems in industry (Monostori et al., 2006[32]). Rockwell Automation even develops agent-based systems where the agents run inside the PLC itself (Mařík et al., 2005[33]) instead of on separate computers. Self-properties in assembly systems are only now starting to be regarded as beneficial. In fact, until recently, self-organization and emergence have been forbidden concepts in the assembly domain under the argument that one would not like industrial manipulators to come up with surprises in a production line. But they do, and always have done: error-recovery and fault diagnosis have tried to deal with this for decades without understanding the fundamental sources of such disturbances and how to exploit them rather than counter them!

The next two topics: self-organisation and emergence are, as stated above, fundamental in the context of future control. In areas such as biology and artificial life, emergence and self-organization have been discussed for many years and accordingly, definitions exist. Also for Multi-Agent Systems, these topics have been investigated (2006, Brueckner et al., 2005[34]).

**Self-Organization**

Reasons for implementing self-organization in EAS are to minimize and facilitate user interaction, i.e. to hide complexity and increase system autonomy. Building and configuring a system composed of numerous entities with multi-lateral interactions is a highly complex task; the more autonomy the system has, the easier it gets for the user. Production systems tend to have many components of diverse nature which interact in many coupled ways. Agents need the capacity of organizing their collaboration themselves, in different forms and compositions, according to the needs, without passing through a central coordination point.

Self-organization is robust and adaptive with regard to its environment. In presence of perturbations and change, the system is capable of maintaining its organization and functionality. This means in practice that the control system should be capable of handling problems and if necessary finding alternative production ways.

In natural systems, the “target behavior” is an attractor and the system will again converge towards it. A major challenge in manufacturing applications is to let the system self-organize and at the same time,
determine its behavior. Different from natural self-organized systems, artificial systems respectively EPS may require a kind of leader, a broker or (eventually human) decision maker. The control influence of this authority may be punctual in time and scope, e.g. at important strategic points.

**EMERGENCE**

Complex systems most often consist of at least two different levels: the macro-level, considering the system as a whole, and the micro-level, considering the system from the point of view of the local components. Local components behave according to local rules and based on preferably local knowledge; a representation of the entire system or knowledge about the global system functionality is neither provided by a central authority nor reachable for the components themselves. They communicate, interact with each other and exchange information with the environment. From the interaction in this local world emerge global phenomena, which are more than a straight-forward composition of the local components' behaviors and capabilities.

Typically, there is a two-way interdependence: not only is the global behavior dependent on the local parts, but their behavior is also influenced by the system as a whole. Emergent phenomena are scalable, robust, and fault-tolerant, i.e. insensitive to small perturbations and local errors as well as component failure, thanks to redundancy. They exhibit graceful degradation, meaning that there is no total break-down because of minor local errors.

Emergence has always existed and will continue to exist. It is the driving force behind evolution. Many of the ideas about tackling emergence date back to the 1950s, and have continuously been re-invented, classified, challenged and debated. Nothing has proved their inability to date. However, within the manufacturing topic, alternative attempts to cope with only undefined parts of the effects of emergent behaviour have failed. In other words, emergent behaviour is nothing other than the resulting system behaviour when subjected to disturbances and other unpredictable events.

In adaptive assembly systems, there is a fundamental assumption that has been overlooked: if the system is adaptable, its smaller constituents (equipment) must exhibit a far quicker adaptability: in fact, they need to evolve to the changing dynamics, offer mutations and chose the most successful alternative. Exploiting emergent behaviour may lead to the capture and use of new characteristics that may lead to an advantage. *Basically, evolution occurs all the time: rapidly with smaller entities and slower with more complex ones. The faster the capture and exploitation of emergent properties, the quicker the adaptation.*

Manufacturing and assembly systems are only a single stage of a very complex system which comprises products, different companies, logistics, software and hardware, people of varying skills and notions, and so forth. These are unquestionably complex systems. Assembly systems of a modular nature consist of many individual, often small-scale elements that have to be brought together into larger scale systems with a massive network of connections at different levels. These are obviously complex systems made up of simpler elements. And they must perform robustly and efficiently in time: be sustainable both economically, ecologically and socially.

Since complexity is currently being tackled fairly successfully (if not unanimously...) by multi-agent techniques for emergent behaviour ([35], [36], [37]), the authors will therefore underline the need to start considering evolvable systems as complex systems that require moderate emergence (as defined by Clark[38], Bullock & Cliff[8]).

The Evolvable Assembly and Evolvable Production paradigms have emerged to clearly explore these technologies, advocating the use of biologically inspired self-organizing multiagent systems for production systems. EUPASS, as being part of this endeavour, should definitely enforce this direction of work.
THE STRATEGY/VISION

The strategies listed in this section are not aimed at the engineering community of companies alone. It is fundamental, and of urgent concern, that these strategies be read and analysed by the management of system integrators and system suppliers first and, subsequently, the management of mid-sized and large companies.

This Roadmap identifies three main directions that R&D may take, depending on the particular needs, as defined below. Note, however, that most of these main needs ARE intertwined.

1. **Size of devices**: there is a clear lack of production equipment for pure micro devices (i.e. gears of 1mm diameters, etc.). These products, however, do not represent the bulk of profit-yielding products for Europe, a class of products still dominated by macro and meso products. This is a very dedicated goal for R&D.

2. **Business models**: whatever the products, sales volume, or market spread, there still exists a clear lack of business models. This is particularly relevant when deciding what to outsource or not, what to automate or not, and what one should focus on in terms of advanced automation investments. This is an urgent need and a general goal for R&D.

3. **Evolvability/adaptability demands**: pure adaptability to dynamic changes, from a holistic and not purely system-perspective, is greatly needed. This is true for different batch sizes, product sizes, and system sizes. R&D predicts that evolvability may be achievable for all products sizes down to pure micro, where extreme demands would set new constraints (see different set of forces that influence processes, etc.). This is a general goal for R&D.

Adaptability or sustainability need to be reproducible at will, and based on solid business models. Therefore, the conventional approach to developing assembly systems must be abandoned: Creating a system architecture based on a limited set of practical experiences is nothing other than a one-off-solution for a limited set of specific requirements. Tools which may accelerate the development of a system architecture are only a partial solution, as the basis upon which they operate (driving parameters), need to be adjusted to the idea of evolvability rather than pure configuration. What is urgently needed is a methodology based on an open, reusable, Reference Architecture that can enable any user to adhere to, or develop, their own evolvable, rapidly deployable, solution for another product segment. So, a methodology is what is truly required, and this is, as shown below, the result of combining a number of specific methodologies in order to accommodate the HOLISTIC and OPEN attributes. Let us consider the fundamental technologies that may be required.

### Table 5- Existing Technologies and Methodologies

<table>
<thead>
<tr>
<th>Topic / Technology</th>
<th>Current Technology Level</th>
<th>Present Level of Integration within Assembly</th>
<th>Available Implementation Methodology or R&amp;D project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconfigurability</td>
<td>Medium-High</td>
<td>Medium-High</td>
<td>Reconfigurable Assembly Systems, Flexible Assembly. EUPASS, HMS, Flexline attempting to address this.</td>
</tr>
<tr>
<td>Plugability</td>
<td>Medium-High</td>
<td>Low-Medium</td>
<td>No. Flexline™ and ModuTech only industrial approaches to come close.</td>
</tr>
<tr>
<td>Distributed Control</td>
<td>Medium-High</td>
<td>Low</td>
<td>CoBaSa®, ABAS®, Holonic Manufacturing Systems*, DPWS*, Evolvable Assembly System†. EUPASS attempting to address this.</td>
</tr>
<tr>
<td>Emergence</td>
<td>Low-Medium</td>
<td>Very Low</td>
<td>Evolvable Assembly Systems (theory only)* is the only paradigm attempting this at present.</td>
</tr>
<tr>
<td>Integrated Business Models</td>
<td>High</td>
<td>Low</td>
<td>?? no information available</td>
</tr>
<tr>
<td>Reference Architecture behind methodology</td>
<td>High</td>
<td>Low</td>
<td>Evolvable Assembly Systems†, ABAS®, Holonic Manufacturing Systems*</td>
</tr>
<tr>
<td>Complex Systems Engineering</td>
<td>High</td>
<td>Low</td>
<td>see NASA...EAS attempting</td>
</tr>
</tbody>
</table>

* = partially available, not industrially verified.
‡ = being developed within an industrially-supported project.

The table above clarifies that there are solutions, technologies and approaches available for further development in only a given range of factors. Business models, true plugability, ambient intelligence, process
formalisation and modular precision solutions remain elusive at implementation methodology, although all are very relevant to attaining truly evolvable assembly. This basically means that isolated solutions may have been developed and tested but that industrially viable products with such characteristics still do not exist or remain exorbitantly expensive. Evolvable Assembly Systems offers the opportunity to attain these goals, but, as has been defined, the set of guidelines that define HOW one is to attain such characteristics need to be re-asserted as a major priority. To achieve this, the Gaps mentioned earlier need to be quelled and the details given in the conclusions below taken as R&D directives.

Conclusions:

The preliminary conclusions given in the First Draft Roadmap (Deliverable 1.5b[41]) document, after a review of the state-of-the-art, clearly pinpointed similar issues:

"For improving the re-usability of modules, the following issues are proposed as vital:

- global standards for the interfaces should be applied to as great an extent as possible, or developed.
- the solutions to date provide attempts at short reconfiguration time from a mechanical point of view, but to achieve truly fast production changeovers, more focus should be given to the control aspects (due to the needs posed by emergence; see next section).
- finalising the set-up of the assembly systems underlines the importance of information aspects (configuration & control), since configuration & control lie at the heart of emergence (poor process knowledge = failure).
- each system module should provide a description of its skills in computer understandable format; this would allow faster module selection for the user needs and vital information for the configuration of the assembly system."

Therefore, to attain true adaptability, sustainability and re-configurability with zero down-time, the control issues become of extreme importance. However, control solutions need the supporting infrastructure to attain the required adaptability, an issue often forgotten. This means architectural frameworks, standards and formalised processes.

Considering the earlier table contents, and the facts derived from the previous sections, the conclusions may be listed as follows:

1. European R&D needs to focus on the key factors behind rapid deployment of modular systems:
   i. referential architectures,
   ii. advanced interfaces, and
   iii. distributed control solutions.
2. European R&D needs to seriously re-assert the validity of scientific innovations that may support adaptability, evolvability and fault-tolerance. Emergent behaviour, multi-agent architectures, and self-diagnosing systems should be highlighted.
3. European R&D in adaptable/sustainable assembly systems needs to re-establish a common vision and develop its main deliverable: a methodology that describes how one may achieve an evolvable system solution.
4. Underline that adaptability stretches from autonomous setups to self-modifying system components: the modules/components need to be rapidly & extremely adaptable (evolvable) in order for the assembly system itself to become adaptable.

**Evolvable Assembly Systems**

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</thead>
<tbody>
<tr>
<td>Common vision established</td>
<td>Reference Architectures</td>
<td>Self-modifying modules</td>
<td>Distributed Control applied</td>
<td>Emergence &amp; self-organisation</td>
</tr>
</tbody>
</table>

**Evolvable Assembly Systems**
References

1. The NEMI Roadmap; NEMI, National Electronics Manufacturing Initiative (USA), http://www.nemi.org/Roadmapping/index.html
5. "SMEs in Focus- Main results from the 2002 Observatory of European SMEs", submitted to the Enterprise Directorate-General of the European Commission by KPMG Special Services; Observatory of European SMEs, ISBN 92-894-4878-4
12. R.Meredith; " Giant sucking sound"; www.forbes.com; October 6, 2003
13. R.Ellis, B.L.Lowell; " The outlook in 2003 for information technology workers in the US"; Commission on Professionals in Science and Technology; September 2003
15. Weber, A.; " Electronics Assembly: The Pros and Cons of Outsourcing"; www.assemblymag.com/Articles/Feature_Article/f291390b76d5c9010VgnVCM100000f932a8c0____ - 2003/02/01
25. "Manufuture RTD Roadmaps", Prof. Engelbert Westkämper, FhG-IPA, Germany
26. US National Academy of Sciences;


41. "First Draft Roadmap-deliverable 1.5b"; Project Report-Public, Document 1.5b, EUPASS-Evolvable Ultra Precision Assembly, NMP-2-CT-2004-507978; October 2005

Notes