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Afifa RAHATULAIN[1]
Mauro ONORI[2]

PRODUCTION SYSTEM INNOVATION THROUGH EVOLVABILITY: EXISTING CHALLENGES & REQUIREMENTS

Recent mass-customization trends and increasing global competition has posed many challenges for the current manufacturing industry, particularly in Europe. Having a quick response to market fluctuations and adapting to customer demands while maintaining shorter lead times and low cost are a few of the major challenges. This paper focuses on Evolvable Production System (EPS), which is one of the emerging cyber physical systems in the manufacturing domain to address these challenges. The main objectives of this paper are: a) to identify the potential areas which may require modifications for the wide-scale implementation of the new manufacturing paradigms in the existing industrial setup, and b) to investigate the risks, challenges & opportunities associated with the concept realization in industry within each identified area. The results are derived based on both an extensive literature study as well as a survey carried out at an SME.

1. INTRODUCTION

The dynamic market conditions, increasing global competition and variance in customer demands are a few of the factors demanding significant changes in the traditional manufacturing approaches. There is a need for achieving shorter lead times, reduced down-times, low investment costs, increased safety and security levels for networked architectures, and life-cycle assessments based on triple bottom line [27],[38]. The results from recent industrial and research efforts such as, Flexible Manufacturing Systems (FMS) 44], *Reconfigurable Manufacturing Systems (RMS)* [23], *Holonic Manufacturing Systems (HMS)* [15] and *Evolvable Production Systems (EPS)* [24] have shown the potential of using modular, intelligent and adaptable systems to deal with these challenges [1],[9],[25],[27].

This paper mainly focuses on EPS which is one of the most promising emerging paradigms aimed at revolutionizing the manufacturing industry by incorporating adaptability, self-reconfiguration and intelligence at the shop-floor level [26],[28]. The main objectives of this paper are:

[1] SenseAir AB, Sweden
[2] KTH, Royal Institute of Technology, Department of Production Engineering, Sweden
[*] E-mail: afifa.rahatulain@senseair.se

1. To identify the potential areas requiring modification for a wider industrial acceptance;
2. To investigate the challenges and risks associated with each area.

The remaining paper is structured as follows: Section 2 provides a brief introduction to the EPS paradigm. Related work and research methodology are discussed in sections 3 and 4, respectively. In section 5, the potential areas and their associated challenges and risks are detailed. The paper is concluded with a brief discussion in section 6.

2. EVOLVABLE PRODUCTION SYSTEMS (EPS) - AN INTRODUCTION

EPS is one the most promising emerging paradigms among the next generation of production systems. Its modular architecture with intelligent, agent-based and distributed control, offers real-time *Plug & Produce* at the fine granularity level (i.e. adaptability at the level of sensors and actuators) [26]. Fig. 1 shows the inspirations from other research domains enabling the concept of evolvability in production systems [25].

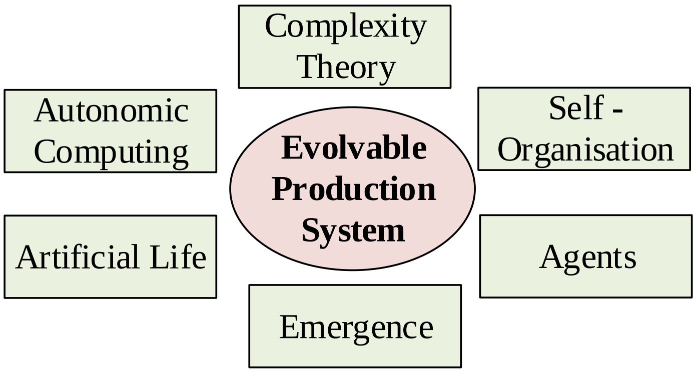

Fig. 1. EPS Research Enablers [25]

In comparison to the existing systems having limited configuration capabilities and handling a predefined set of products, an EPS offers adaptability and scalability according to the changing product requirements and market demand, respectively, by enabling run-time modifications and dynamic upgradation of the system.

The core of EPS is based on the concept of ‘skills’ which are required to perform production processes. The pre-configured standard modules offering distinct skills are added and removed from the system as per process requirements of a particular product. When a new product or its variant is introduced, the only requirement is to plug in the required skill module and start producing. It requires minimal engineering efforts as compared to the existing systems, due to the self-managing properties incorporated in the system. This process-oriented approach makes the system more focused towards the manufacturing activities & tasks and directly influences the product design process instead of being itself product-dependent.

State-of-the-art of EPS

A few of the recent advancements related to EPS technological development include; the concept of a *reference architecture* [24],[28], an *ontology* to support evolvable assembly systems comprising of product, process, and assembly equipment domain [2],[11], utilization of JADE (Java Agent Development Environment) platform for implementation of *agent-based control architecture* [22], a *visualization tool* for retrieval of the information exchanged between agents [21], a *dynamic skill-configuration methodology* [40], simulation tools for *self-organizing algorithms* [36], etc.

A *demand-responsive planning* architecture has also been introduced to support the strategic decision-making for operational management in EPS [14].

The true potential of a technological innovation can only be realized if it is supported by a successful business model [13],[16],[20]. Hence, an *innovative business model* supporting the re-usability of intelligent equipment modules from a pool of shared resources has also been proposed to fully exploit the true economic potential of EPS and to maximize the associated benefits [3].

The re-usability of the equipment modules facilitated by the process-oriented approach of EPS, not only adds to the economic advantage, but also contributes to the long-term environmental sustainability by reducing raw material costs for new equipment manufacturing.

Despite the advancements and developments in this area, and several successful industrial demonstrators, the overall acceptance of these emerging production paradigms at a larger scale is limited by certain factors. This paper discusses in detail some of the major issues related to the industrial implementation of these paradigms, with main focus on EPS.

3. RELATED WORK

The existing literature on EPS mainly focuses on its technical aspects and business & planning models as discussed in section 2. To the best of authors' knowledge there exists no work which specifically targets EPS in the context of investigating the challenges associated with its industrial realization.

This paper, however, can be considered as a complement to the results from previous research efforts in identifying the challenges faced by the industrial agents for the acceptance in industry [5],[30],[32],[33],[34],[35],[46]. It particularly it evaluates the identified challenges in the context of evolvable production systems and provides the pros and cons of each. In addition, challenges in a few more areas such as, functional safety, information management, system integration, ethics, and IPR & legislative requirements for adaptable systems, in general, are also proposed and discussed.

4. METHODOLOGY

An iterative methodology has been adopted to achieve the objectives of this paper. To identify the potential areas needing modification and further research & development efforts, the first step was to conduct a generic literature study with the terms ‘Evolvable’ and ‘Adaptable’ in the context of production, manufacturing and assembly systems as the main criteria. After the identification of main areas, a reiteration of the literature review process was carried out for achieving objective 2, i.e. investigation of challenges related to these areas. The selected literature was further narrowed down by focusing on the production systems with multi-agent control approach.

To further strengthen the work, a brief survey was also conducted at an SME (SenseAir AB) through short interviews, to complement the results and findings. One of the main reasons for selecting this SME is its active involvement & interest in the research related to EPS [6],[7],[45]. The views and comments were recorded with the consent of the interviewees and are summarized in appendix A.

The results from the existing literature and survey were used to support and enhance the initially identified areas. Finally the challenges within each area are elaborated and discussed in detail in the following sections with reference to the similar challenges from other research domains.

5. CHALLENGES AND REQUIREMENTS FOR THE NEXT GENERATION MANUFACTURING PARADIGMS

This section discusses in detail the challenges and requirements within the identified areas in context of EPS. Overall seven major areas are identified following the above mentioned methodology, namely; technical aspects, design & development process, multi-disciplinary information management, adoption of existing industrial standards and protocols, business aspects, IPR and legislative issues, and ethical concerns. Each area is further classified into sub-parts. The EPS viewpoints mentioned in reference architecture [24] are the major basis for the classification. In addition, the industrial acceptance factors mentioned in previous surveys [32],[35],[46], and related issues in similar research domains [20],[39],[41],[43] are also taken into account for the classification. For example, the technical aspects mentioned in ‘i’ related to hardware, software and communication network are evaluated further for four main aspects, namely; safety, standardization, limitations in flexibility and cost. In addition, a security-related challenge is also included in the communication network field. The remaining areas from ii to vii are discussed individually providing details of the associated challenges, respectively.

i. Technical Aspects

a. Hardware

- ***Safety*** To achieve a highly flexible and autonomous system, it has to be equipped with advanced sensing mechanisms to react timely in case of unexpected events / emergent behaviours. This increases the system complexity and in turn makes the system more costly. Thus, there exists a major trade-off in minimizing the system cost and increasing its autonomy within the safety limits, at least with the available equipment and existing infrastructures.

- ***Standardization:*** There is a need to develop standardized hardware modules with open interfaces to avoid compatibility issues during system integration. This remains a challenge until the benefits of adaptable systems are fully recognized by the industry.
- ***Limitations in flexibility***: The mechanical equipment available today is not easy to move and re-organize physically. For implementing certain reconfiguration and self-organization algorithms adopted from artificial intelligence (AI) and bio-inspired systems to achieve highly reconfigurable systems, this remains a major challenge.
- ***Cost:*** The main challenge associated with the mechatronic hardware development is to provide modules with embedded intelligent controllers while maintaining the equipment cost to a minimum. The decentralized approach for EPS requires a lot of activities which at present are carried out at design time, such as optimization. This can lead to the requirement of a controller having high processing power, memory, etc. Each added functionality contributing to the agility of the equipment increases the cost, making the overall system less economically viable with existing equipment and facilities.

b. Software

- ***Safety:*** At present, the general 'safety related' industrial systems programming does not support evolvability and agility; i.e. dynamic addition and removal of components not known at the time of software compilation. In addition, it will also be a challenge to differentiate between the safety- and non-safety related softwares and to ensure the safety of the system is not affected by non-compliant softwares.
- ***Standardization:*** *S*tandardized modules and interfaces are required between different software developers or service providers. There is a need for an explicitly defined architecture to be followed by the industry for emerging manufacturing paradigms (such as an open architecture defined for automotive industry [8].
- ***Limitations in flexibility:*** The existing protocols and message exchange formats for multi-agent systems (MAS) are not currently optimized for efficient performance in real-time applications [31],[33]. This issue, if not resolved, may remain a major obstacle in the acceptance of EPS by the industry at a larger scale.
- ***Cost:*** A change in conventional automation programming towards agent-based programming required a whole new set of expertise not widely available within the industry at present. This adds another challenge to make the paradigm shift cost effective.

c. Communication Network

- ***Safety:*** Communication delays and failures affecting the synchronization of system modules during run-time operations may cause serious consequences leading to chain of unexpected events. The challenge is how to calculate such performance parameters during run-time. The deployment of a software agent with reference to its physical placement in the system in a complex networked system is one example of evaluating performance parameters in a network. In case of a production environment this may cause serious synchronization issues, if not addressed properly.
- ***Standardization:*** The standardization of the communication protocols and interfaces for the EPS approach is another major challenge that needs to be addressed.

- ***Limitations in flexibility:*** The limitations on the number of maximum modules in a network, real-time network constraints, and communication delays/failure are to be given importance when considering general networked architectures, and so is the case with EPS.

  Security: Assurance of network security over which the modules are communicating and the information is being transferred is another challenge faced by EPS. Apart from the security threats as encountered by any general networked system, an EPS is more vulnerable to data security and hacking issues due to its online database. The information regarding product parts, available skills, machine parameters, required manufacturing processes, etc. in the online EPS repository is available to be accessed by the system modules over the communication interface. Therefore, there is a possibility of data misuse in case of a cyber-attack. This could even lead to serious proprietary issues if the information is illegally transferred to the competitive companies. Moreover, unauthorized access to the network may also result in altering the desired functionality of the system causing malfunctions. There is also a possibility of abuse of the physical equipment for causing harm or injury to the personnel. In case of a production environment where hazardous raw materials are involved, the abuse of the system may even have fatal consequences.
- ***Cost:*** The need for reliable protocols, secured networks and faster communication requires significant increase in the overall system cost. Thus another trade-off has to be made between network security and cost which remains a challenging task.

ii. Design and Development Process

- ***System Specifications:*** One of the foremost activities in any development process is defining the system specifications. The major challenge in EPS is to specify a system which is evolving with time and maintaining the changes in the specifications throughout system's life-cycle.
- ***Verification and Validation (V&V):*** The execution of validation and verification (V&V) activities in an evolvable system with real-time configurations during the design phase is a challenging task. [39],[41]. As compared to modern practices where verification and validation is performed before commissioning, a lot of activities will be carried out by the machines themselves and at run-time. Thus risk management with agile approaches becomes significantly important.
- ***Tool chain and Tool integration:*** There is a plethora of design tools available for various purposes depending on the user requirements. For example, Matlab /Simulink for control algorithms, Agent-Based Modelling (ABM) tools for discrete events, etc. There is a need to find synergies between the activities and integrate to find a better development flow [43]. This is a challenge in general for systems development, and becomes even more challenging for agile systems like EPS.
- ***System Integration:*** There is also a need for a well-defined integration methodology [33] to support the overall development process. Hence, the need for open and standard interfaces becomes evident.

iii. Multi-Disciplinary Information Management

The basic structure of the EPS knowledge model (KM) [24],[26],[28] is shown in Fig.2. It has been categorized into different knowledge domains showing the involvement of various stakeholders, each contributing towards the development of a complete & comprehensive knowledge model. This includes *enterprise knowledge*, *product knowledge* (including production system design), *execution knowledge,* and *learning knowledge* domains. The information from each domain can be integrated and represented using common domain ontology and standardized knowledge templates, where the knowledge templates are defined as "re-usable diagrams, graphs, objectives and rules describing the system functions" [25]. This common domain knowledge can be used further to address the different views & viewpoints in EPS [18],[25].

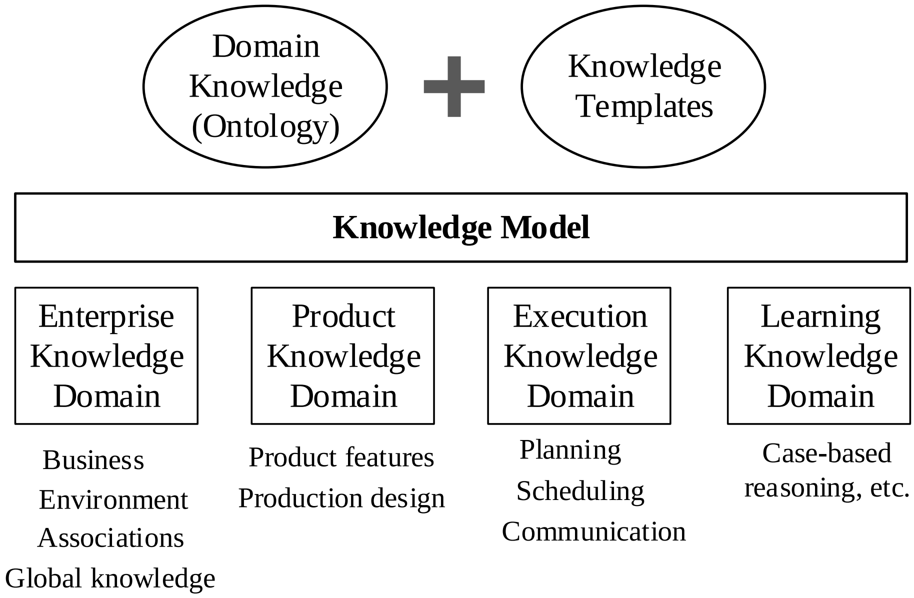

Fig. 2. The EPS Knowledge Model [28]

- ***Completeness of Information*** Being a knowledge-based system, the accuracy of the run-time decision-making and the extent of self-management in EPS is dependent on the completeness of the knowledge model [37].To effectively utilize the developed EPS ontology for addressing various system views (e.g. behavioural and structure views), there is a need to focus on its completeness such that it includes comprehensive knowledge from each of the domains. Moreover, the maintenance of knowledge model should be such that it is updated autonomously with the changes in the domain knowledge [30],[34].
- ***Efficient Information Transfer:*** Another important challenge associated with knowledge-based systems is related to data acquisition and information management [37]. With autonomous industrial systems like EPS, information management is even more important due to increased system complexity and involvement of various stakeholders. There is not only a need to provide an efficient information transfer within and outside the respective domains but also information traceability should be made effective. Any discrepancies in the information flow may result in increased costs, unexpected delays and in some cases may even be the cause of fatal safety hazards.

iv. Adoption of existing Industrial Standards and Protocols

Existing industrial standards and protocols are a result of several years of experience, history of accidents and industrial statistics. The greatest challenge in this area is the modification of various standards for the accommodation of the evolvability concept [35], [46]. This is not trivial, particularly from a safety perspective and the biggest risk is the non-acceptance by the standardizing organizations due to the uncertainty and emergence factor associated with such systems [3],[35]. However, the modifications in the standards will certainly result in a paradigm shift bringing a small- scale revolution in the industry. This area is of utmost importance and requires major efforts for proving EPS's viability as the next generation manufacturing paradigm. Following are a few examples of the existing industrial standards which require modifications to accommodate the agile approach:

Functional Safety (IEC 61511, IEC 61508): Nearly all industrial systems can be considered as safety critical systems [4], as when physical machines are involved, a slight miscalculation resulting in abrupt movements may have fatal consequences. There exist several standards related to safety. In particular, IEC 61511 and IEC 61508 or their derivatives like EN ISO 13849 are related to functional safety. These standards specify integrity levels for different safety functions. However, in a self-managing system with autonomous machines capable of intelligent decision-making with minimum human interference, the identification of safety functions and their requirements, like integrity level will be a non-trivial task. Furthermore, there is a need for alignment and integration of processes from functional safety standards during the generic development of EPS. One effort in this regards which can be adopted from the automotive industry is the alignment of ISO 26262 with EAST-ADL [10] where the latter can be used for dynamically- configurable automotive systems.

- ***PLC Programming Languages (IEC 61131-3):*** The control architecture of EPS is based on multi-agent systems [22]. Thus, the existing programming standards need to be updated to fully exploit the EPS potential. Inability to modify the standard accordingly may result in reluctance by the industry as non-standardized practices are usually not preferred, in general.
- ***Enterprise to Control System Integration (ISA 95):*** ISA 95 establishes the standards and protocols required to integrate the control systems at the shop floor level to the operations at the enterprise level. It may facilitate the market openness and vendor compatibility by integrating the existing automation standards with the agile approach [35].
- ***Distributed Control and Automation (IEC 61499):*** This standard is aimed at providing an open architecture for the next generation of distributed control and automation. Functional Block is the main concept in IEC 61499 which acts as an interface between different distributed modules. There is a need to incorporate the EPS architecture requirements into this standard or to make appropriate changes in the existing EPS according to the concepts provided in the standard.

v. Business Aspects

The biggest challenge in the adoption of the new business model for EPS is in changing the organizational structure and the underlying mental models. This is termed as “strategic re-architecting” by Pisano [13], i.e. challenging the existing industrial architecture. Moreover, the technology readiness level (TRL) and the concept maturity directly affect the implementation of the new business model. Another business-related aspect is the unforeseen costs required for maintenance, personnel training and long-term support for intelligent, agent-based manufacturing approaches [35] which affects the adoption of such new paradigms.

vi. Intellectual Property Rights (IPR) and Legislative Issues

The fact that the system consists of several individual modules (not necessarily from a single provider) and the equipment is not owned by the industrial user may give rise to issues related to ownership and responsibilities. Due to the emergent nature of the system, there can be unknown situations, which may even result in serious consequences. The legal responsibilities in such cases are to be explicitly defined. Also, the back tracking in case of a system failure may not be trivial in open architectures, such as EPS. For example, the equipment may function well individually but their integration under certain conditions may give rise to some unexplained behaviour. Thus, the importance of development process becomes even more evident for such systems. The ultimate opportunity in using such systems is however, the benefits reaped from the open innovation concept.

vii. Ethical Concerns

The emerging autonomous technologies are vulnerable to many open questions regarding their ethical implications. There always exist some compromises between the risks and benefits of the new technology, such as temporary advantages versus long term risks, group benefits against individual losses, replacement of human workforce by machines, blame shift (e.g. people considering machines responsible for the mistakes and delays), etc. [42]. The utilization of self-learning robots, intelligent assembly equipment and other autonomous machines in parallel with the human operators in the production facilities is expected to be the norm of the future manufacturing [17]. The machines shall not only be used for performing physical tasks related to service and maintenance but shall be extensively employed for making independent control and logical decisions, such as in adaptable manufacturing approaches. This increasing use of autonomic computing can be viewed as an extension of human cognitive capabilities analogous to the use of machines for extending human physical power in industries [12]. Thus there arises a need for the adaption of an ethical code of conduct for these emerging production paradigms where the steering responsibility is being shared between humans and intelligent machines.

Table 1 provides a summary of the inferred results discussed above along with the associated opportunities and risks within each area.

Table 1. A Summary of the existing challenges, risks and opportunities in EPS

S. No.	Area of interest	Challenges	Risks	Opportunities	Influenced Areas
1	**Agile Control System**				
1,1	Hardware (controllers, I/O modules, sensors, etc.)	Low cost equipment, advanced sensing mechanisms	Safety and service issues	Robustness, Predictive Maintenance	Industrial standards, System integration and IPR
1,2	Software	Programming languages, standardized software modules and interfaces	Real time constraints	Self-Management	Industrial standards, System integration and IPR, Information management

1,3	Communication	Standardized protocols, Data security	Network delays, real time constraints, misuse of information	Open Innovation, Online /Remote access, competitive market	Industrial standards, System integration and IPR
2	**Development Process**				
2,1	Verification & Validation Activities	V&V for real-time configurations and emergent situations	Fully functional EPS might not be realized	Paradigm shift	Agile Control System, System Integration, Information management
2,2	Design Tools	Integration methodology, design support	Compliance from tool vendors	Efficient development process	Agile Control System, System Integration, Information management
3	**Multi-Disciplinary Information Management**				
3,1	Knowledge Model	Common stakeholder understanding /Ontology	Completeness and usefulness	Efficient development process	Agile Control System, Development Process, System Integration, Business Model
3,2	Information Flow & Maintenance	Information Traceability	Unexpected results (increased cost, delays,etc.) due to information discrepancies	Automation of information flow and robust development process	Agile Control System, Development Process, System Integration, Industrial standards
4	**Industrial Standards & Protocols**	To accommodate evolvability aspects	Non-acceptance by standardizing organizations due to uncertainty	Paradigm shift	
4,1	Functional Safety (IEC 61511, IEC 61508)	Alignment & integration of standard processes	Safety Requirement: Verification & Validation , not possible due to run-time configurations	---	Agile Control System, Development Process, System Integration, information management
4,2	Programming (IEC 61131-3)	Updating standard	Non-standardized methods not preferred by industry	---	Agile Control System, Development Process
4,3	Enterprise-Control System Integration (ISA 95)	Adoption of EPS concept (technology + business model)	Non-compliance may result in industrial reluctance	Aligned vertical and horizontal integration	Agile Control System, Development Process, System Integration, Business Model, Information management
4,4	(Distributed Control & Automation (IEC 61499)	Incorporation of agent concepts	Non-standardized methods not preferred by industry	Standardized industrial practices for distributed control	Agile Control System, Development Process, System Integration
5	**Innovative Business Model**	change in existing industrial organization and underlying mental models	Availability of modules for leasing : supply issues, timing issues	Environmental sustainability, significant reduction in capital investment	System integration, PR & Legislative Issues, Industrial standards and protocols, Information management

6. CONCLUSION

Evolvable assembly systems are "*fully reconfigurable mechatronic systems that exhibit emergent behaviour"* [25]. Several benefits offered by EPS include, reduced down-times, shorter lead times, robustness, dynamic scalability, low capital investments, sustainability, process-based system, etc. Despite being one of the most promising paradigms in the next generation manufacturing systems, there are several challenges that need to be addressed before this concept is realized at a wider scale in industry.

Updating the functional safety standards and the incorporation of EPS architecture in the existing industrial programming standards is considered as one of the most important areas identified in this paper, needing significant research activities. On the other hand, the most developed area in which most of the EPS advancements have been made is identified to be the agile control system. The industrial prototypes developed using the agile control architecture [11],[22],[29],[45] and the configuration & visualization tools [21],[36],[40] can prove to be the initial step in the implementation of EPS in industry.

To cope up with the existing manufacturing challenges, stand-alone technology cannot be a problem solver. Adaptable control system, innovative business model, flexible production strategies and increased levels of automation are all the factors needed together to support the innovation process through evolvability. All these factors favour EPS as a possible paradigm innovation, i.e. *changing mental models and challenging the existing industrial architecture to provide an innovative process for adaptable manufacturing.*

The evaluation of EPS presented in this paper is the first step towards identifying the associated challenges. The issues identified are based on the challenges discussed in the available literature as well as from similar issues in other research domains.

Moreover, the survey served as another tool in identification of challenges and provided some important reflections. For example, the answers vary depending on the age group, with relatively younger people (30-45 years) accepting the idea more openly and considering it practical enough to be adopted by an industry by overcoming challenges. People belonging to relatively older age group considered intelligent machines in industry as science fiction.

Another observation was that the people with experience of working at a shop floor considered this approach having more risks than opportunities at present. While the interviewees related to product design were more positive in having a flexible system capable of producing literally anything without limitations. A more comprehensive survey involving more companies (both SMEs and large industries) and personnel from different areas of expertise and age group can provide a better perspective and further strengthen the results provided in this paper.

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APPENDIX A
FROM CONVENTIONAL TO EVOLVABLE PRODUCTION SYSTEMS
(A survey from SenseAir AB)

SenseAir AB is a medium sized company located in Delsbo, Sweden, and is one of the world's leading manufacturers of Non-Dispersive Infrared (NDIR) CO2 sensors and controllers. Like other SMEs, SenseAir faces several challenges due to the increased competition in the global manufacturing market. The main emphasis is to strive towards adopting sustainable and agile production solutions considering social, ecological and economical aspects. However, to embrace the emerging technological innovations in the traditional production setup, identification of the existing strengths and weaknesses and impact analysis of modifications on the system elements is required.

Survey Methodology

To complement the results presented in this paper, a brief survey was conducted at SenseAir by interviewing the personnel from different departments (Production, logistics, product design, system developers, and change management) as well as different age groups. All the interviewees were explained the EPS concept with its technological and business aspects and then asked questions individually according to a prepared questionnaire. The first question is an open question to get a general opinion, while the rest of the questions are based on the identified areas as detailed in section 5 this paper. The views and comments were recorded with the consent of the interviewees and summarized. The questionnaire is as follows:

i. What do you think of the EPS idea in general? What can be the risks, challenges and opportunities if this concept is adopted by SenseAir?

ii. What will be the challenges related to the implementation of proposed business model?
iii. What can be the difficulties in the realization of an agile control system with respect to the hardware, software and communication interfaces used in today's system?
iv. How can the IPR issues and system integration concerns be resolved in EPS as compared to existing systems?
v. Will there be a need for significant changes in the information management process than that used in the current setup?
vi. How do you perceive safety requirements for such systems?
vii. Are you comfortable with the idea of intelligent heavy machines with real-time decision making, working in parallel with humans?
viii. In existing setups, the product is mainly influencing the design of the production systems. What will be the challenges in implementing process-oriented production systems, where the product design is to be modified accordingly?

Observations

The interviews resulted in several interesting observations and some new insights about the possible challenges associated with the industrial implementation of EPS. Though everyone considered the concept as appealing and interesting, some even called it `science fiction' or `future-future system'. The observations varied widely depending on the area of expertise people are working in and also to the age group they belong to. Following is a summary of the insights from the interviews:

i. Changing mental models and traditional mindsets was identified as the most challenging task generally related to EPS. Another suggestion was to utilize some of the features from EPS in the existing work flow at SenseAir. For example, the flexible routing concept for an efficient performance optimization and effective resource utilization.
ii. The Business model was considered quite attractive in terms of reduction in capital investment. However, the supply-to demand ratio for the equipment providers may be a risk. Another point highlighted in relation to the business model was the demographic challenges. The location of a company and the duration for hiring equipment can play an important role in the adoption of the new business model.
iii. The use of advanced sensing mechanisms & feedback systems (e.g. vision systems, RFIDs, etc.) was emphasized to ensure correct functionality and safety of the system. Data security was also considered as a very important issue.
iv. System integration was considered as a major problem if open and standardized interfaces are not used. The views on resource sharing varied quite a lot. While some considered benefiting from external cooperation as the main factor for success in next generation manufacturing businesses, the others were quite skeptical of this approach.
v. The automation of information flow was considered important in both existing and future setups. A common stakeholders' language and standard documentation formats could result in lesser information discrepancies. However, due to lack of efficient information management tools for industrial applications, manual `one-to-one' communication was preferred by a few.

vi. The need for stringent safety requirements and updated functional safety standards was considered most important for autonomous systems like EPS.
vii. Increased industrial automation and need for collaborative robots was generally appreciated and emphasized upon.
viii. More forward thinking at design phase, integration of product design into production development process, Design for Manufacturing (DFM) and modular product design were some of the suggestions to improve the overall development time.

Another important area highlighted during these interviews was the consideration and involvement of the `operators' as one of the major stakeholders in the implementation of EPS. In skill-based systems, the operators who have expertise in certain skills may have job insecurities and may be threatened by the overall skill replacement architecture offered by EPS. Though not directly related to technological implementation, this social issue is to be tackled beforehand. This could otherwise create resistance in adopting this approach.