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COMA'16

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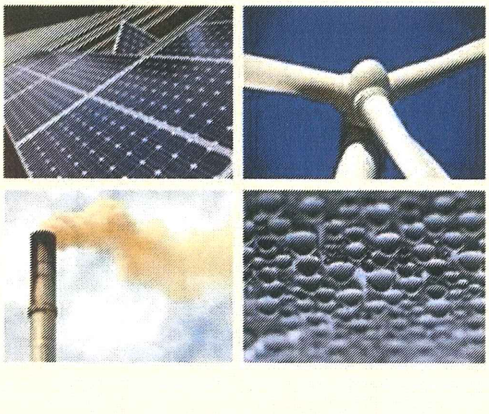
Resource Efficiency for Global Competitiveness



27 – 29 January 2016
Stellenbosch, South Africa

Organised by
Department of Industrial Engineering
Stellenbosch University

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International Academy of Production Engineering

PROCEEDINGS

International Conference on Competitive Manufacturing

COMA '16

27 January - 29 January 2016
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Organised by the
Department of Industrial Engineering
Stellenbosch University

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Strategic Guidance towards Industry 4.0 – a Three-stage Process Model

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Abstract

Manufacturing processes have changed significantly since the early days of the steam engine and Henry Ford's assembly line. After Ford's mechanization and the first digitalization of industrial productions in the 1970s, currently a fourth industrial revolution (commonly referred to as Industry 4.0) is taking place. Industry 4.0 propagates a vision where recent developments in information technology are expected to enable entirely new forms of cooperative engineering and manufacturing. A key idea is that intelligent products and machines – driven by real-time data, embedded software and the internet – are organized as autonomous agents within a pervasive and agile network of value creation. While realizing the potential of these new concepts today's manufacturers experience substantial problems in bringing ideas down to the shop floor. Problems occur mainly due to different perceptions about the principal nature of Industry 4.0, the broadness and complexity of related topics, the expected impact on the strategic and operational level and – as an inevitable consequence – the concrete measures needed to transform towards an Industry 4.0 ready company. In this paper we suggest a three-stage process model to systematically guide companies in their Industry 4.0 vision and strategy-finding process. The proposed model has been applied and advanced within various real-world projects. Results show a strong need for guided support in developing a company-specific Industry 4.0 vision and roadmap.

Keywords

Industry 4.0, Industrie 4.0, Internet of Things, Industrial Internet, Smart Manufacturing, Technology Roadmapping, Co-Innovation

1 INTRODUCTION

Europe's industry is facing substantial economic challenges due to an increasing pace of societal and technological developments, such as decreasing availability of natural resources, natural disasters and warfare, increasing energy prices, increasing age of employees and globalization of markets. Moreover, consumers increasingly demand for improved product-service innovation, product variety, quality standards, support services, and immediacy or order satisfaction.

These challenges need industrial enterprises that are capable of managing their whole value-chain in an agile and responsive manner. To be more specific: companies need both - virtual and physical structures that allow for close cooperation and rapid adaption along the whole lifecycle from innovation to production and distribution [1].

Recent governmental and industrial initiatives sketch a future scenario where recent advances in computer and manufacturing technology are exploited to enable a new way of business operations and especially manufacturing, commonly referred to by the term Industry 4.0 – the fourth industrial revolution (see Figure 1).

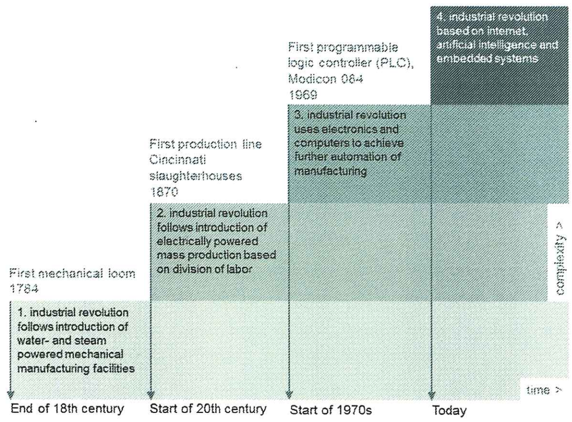

Figure 1 - Four industrial Revolutions (see DFKI 2011)

Accordingly, the internet and supporting technologies (e.g. embedded systems) serve as a backbone to integrate physical objects, human actors, intelligent machines, production lines and processes across organizational boundaries to form an intelligent, networked and agile value chain.

New approaches to business and manufacturing operations are realized through four main focus areas [2]:

- Vertical integration of all layers of a production system
- Horizontal integration of all partners in a value chain
- Lifecycle-engineering across the entire value chain
- Acceleration through exponential technologies

It is obvious that such a futuristic – yet realistic – scenario imposes substantial challenges to today's companies.

On a practical level, especially for small and medium enterprises, challenges arise mainly due to the immense financial resources required for the acquisition of new technology. For example, Germany's companies in various branches are expected to invest 650 million Euros into Industry 4.0-related technologies and applications in 2015 [3].

On a strategic level, experiences from several strategic orientation workshops with various companies have shown that companies face a twofold challenge with regard to the concept of a fourth industrial revolution. On the one hand companies have substantial problems to grasp the idea of Industry 4.0 and relate it to their specific domain. For example, they may not decide whether it is to be understood as a vision or it is rather a mission (ends versus means). On the other hand, they struggle to identify strategic fields of action, programmes and projects to move towards an enterprise in the sense of Industry 4.0. The latter problem is a consequence of the first problem area described – the lack of understanding for the concrete relevance and benefit of Industry 4.0. However, experiences show a general need for guidance in finding a proper strategy towards coping with the challenges imposed by Industry 4.0.

In this paper we suggest a three-stage process model to systematically guide companies in their Industry 4.0 vision and strategy finding process. In section 2 we discuss the concept of Industry 4.0 and summarize the main challenges for European manufacturing companies regarding their transformation towards Industry 4.0. In section 3 we suggest a three-stage process model to systematically guide companies in their Industry 4.0 vision and strategy-finding process. Finally, in section 4 we summarize first experiences from the field.

2 THE CHALLENGE OF INDUSTRY 4.0

Several surveys aimed for shedding light on the rather slow realization of Industry 4.0. A study carried out by IBM in 2015 shows that high investments and costs, the complexity and required know-how, as well as the unsuitability of existing IT-Infrastructure and technologies are the main restraints for realizing Industry 4.0 [4].

Investments are mainly needed for the implementation of modern information and communication technology as well as up-to-date machinery, which should result in a digital transformation of the company's entire business operations. Currently fragmented IT-systems, outdated machine parks and a high degree of manual work disable horizontal and vertical integration along the value chain. These issues are enhanced by the incredibly tiny margins, under which conservative industry operates that prevent investments into uncertain areas such as Industry 4.0. This uncertainty about Industry 4.0 is triggered by the high complexity of the topic and a lack of existing road-maps and guidance towards the realization of the visions and concepts [5] - [6].

2.1 Vision or Mission

The vision of Industry 4.0 propagates a fundamental paradigm shift in production industries, which is characterised by a new level of socio-technical interaction. Small, decentralized networks are acting autonomous and are capable of controlling themselves in response to different situations. These, so called smart factories are embedded in the inter-company value network, which is encompassed by end-to-end engineering, resulting in seamless convergence of the digital and physical world.

The results are smart products that are uniquely identifiable and locatable at all times during the manufacturing process. Smart products are customizable and the incorporation of individual customer- and product specific features into the design and configuration is enabled - at the costs of mass products.

On an employee level, the Industry 4.0 vision propagates, that workers are able to control, regulate and configure smart manufacturing resource networks and manufacturing steps. Routine tasks are taken over by machines, so that employees can focus on creative, value-adding activities [2].

Overall, the vision of Industry 4.0 describes a whole new approach to business operations, and especially the production industries. The sophisticated and complex vision of Industry 4.0 is based on the missionary approach of strengthening Europe's and especially Germany's conventional manufacturing industry - as described in the high-tech strategy the German government has initialized. Advanced manufacturing systems should support Germany's position in competition with the re-industrialization taking place in Asia and the US.

So far, companies seem to struggle when transforming the visionary ideas of Industry 4.0 to a missionary level of increasing the productivity on the shop floor. One reason could be found in the isolated implementation of parts of the Industry 4.0-vision (e.g. implementation of 3D-printing).

Practically, only the collaborative implementation of all the concepts of Industry 4.0 has to be followed to increase the so called collaborative productivity in production industries [7].

2.2 Technology or Methodology

The four main characteristics of Industry 4.0 state "*acceleration through exponential technologies*" as the enabler for horizontal and vertical integration along the entire value chain. However, companies tend to focus too much on the technological aspect in Industry 4.0 in order to attain short-term market advantages.

As Industry 4.0 is based on the concept of cyber-physical systems (CPS), which is mainly a technological approach, aspects such as the modification of organizational structures and processes, the adaption of existing business models, or the development of necessary employee-skills and qualifications are neglected.

The National Academy of Science and Engineering in Germany states that Industry 4.0 is "...best understood as new level of organization and control over the entire value chain of the lifecycle of products..." [2], which describes Industry 4.0 as a paradigm shift in business operations, rather than a technology-based improvement of production capabilities.

The reasons why many companies consider Industry 4.0 a mainly technological improvement are mainly facilitated by the either too complex or too vague descriptions of the new paradigms of Industry 4.0. In contrast, the implementation of aspects such as cyber-physical systems and modern information and communication technology allows for clearer measures to be taken on an operational level.

2.3 Revolution or Evolution

In retrospective, industrial revolutions always lead to a significant increase in productivity which increased the standard of living, and, therefore influenced the society fundamentally. The first three industrial revolutions have been stated as such ex post – triggered by the industry on the shop-floor [8]. In contrast, the 4th industrial revolution is postulated ex ante – triggered and promoted by the government and several related initiatives.

Also the level, where Industry 4.0 comes to action, shifts from the shop-floor to the overall engineering-processes and organizational brainwork within companies. Therefore, the industrial change initiated by Industry 4.0 is addressed highly diverse in literature [9], and no common ground is offered to companies.

Collaboration at all levels and the integration of processes builds the base for increasing collaborative productivity. Therefore, extracting distinct factors such as the implementation of modern technology and holding them responsible for triggering the 4th industrial revolution can result in a narrowed approach to Industry 4.0.

Moreover, during past industrial revolutions, companies reacted to an increased demand from the market which leads to the introduction of mechanical- and mass production. In contrast, the fourth industrial revolution requires companies to act self-reliant, without a clear demand for increased productivity from the market-side [7]. As a result, it is likely that distinct approaches of Industry 4.0 are going to be implemented at faster pace than others (depending on the actual pressure from the market), which indicates a more evolutionary character. However, the implementation of Industry 4.0's concepts in collaborative manners might trigger revolutionary changes in production industries.

3 A PROCESS MODEL FOR TRANSFORMING INTO AN INDUSTRY 4.0 READY COMPANY

To address the above outlined challenges we propose a process model as a guiding framework for Industry 4.0 vision and strategy building. The main goal of the model is to guide companies in developing their specific Industry 4.0 objectives along with a set of measures to reach them. Systematically carrying out the stages will take a company to their company-specific vision and roadmap, enabling a company to clearly communicate respective objectives and take concrete courses of action (see Figure 2). To develop the model we mainly built upon the concepts of co-innovation [10]–[12] and strategic road mapping [13]–[15]. In the following each stage is described in detail.

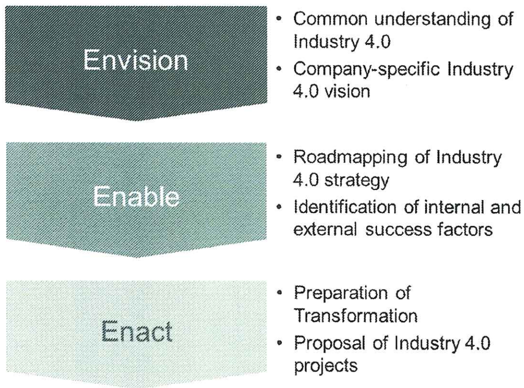

Figure 2 -Three-stage model for Industry 4.0 transformation

3.1 Stage 1: Envision

Within the "Envision" stage a company acquaints itself with the general concepts of the Industry 4.0 vision, develops its own understanding and aligns general Industry 4.0 ideas with company specific objectives and customer needs. The goal of this stage is to arrive at a company tailored Industry 4.0 vision that takes into account peculiarities of the industry and company environment. Stakeholders from top management are primarily involved, but also important business partners and customers are invited to take part in this phase. Broad commitment to the outcomes is reached through a participative approach where members of middle management are actively involved in vision development. At this stage, also external experts are involved to present relevant best-practices and to give important impulses towards vision building.

The stage of vision development is divided into an input oriented phase and an output oriented phase. Within the input phase the conceptual pillars of Industry 4.0 are explained through selected external experts. This leads to a shared understanding from a largely theoretic point of view. Experts' input is followed by a presentation of best-practices and promising examples from the company's domain of action, preferably by practitioners. The latter serves as a way for benchmarking and to raise awareness for the need for immediate action.

Finally, the company's current state of vision is presented through internal stakeholders. Having the big picture of Industry 4.0 and the company's state of vision at hand stakeholders are subsequently advised to develop their company specific Industry 4.0 vision in a collaborative way. The output oriented phase is dedicated to merge visionary concepts and ideas towards a consistent and concrete picture for the company of the future. Within this phase important questions such as the suitability of current business models, the appropriateness of the organizational skillset and the fitness of the current technological infrastructure are questioned and evaluated.

A company running through the stage of "Envision" is encouraged to do this in a collaborative way. In the spirit of co-innovation this means that the company has to extend its focus from the corporation to the whole value network including relevant business partners, suppliers and customers into the vision development [16]. The output of this stage is a company tailored vision for a future end state that withstands future challenges proclaimed by the new industrial revolution. The vision in terms of strategic road mapping answers the question where a company wants to go in the long-term future. The vision of a company should therefore be stated in a semantically unambiguous way, but generic enough not to presume the means (the strategies) for reaching the desired outcome.

The Industry 4.0 vision of a company is not meant to be a carefully programmed business model but should reflect a courageous picture of the company's future that takes into account the company's actual strengths and at the same time expected market, technological and societal developments. E.g. a car manufacturer that develops a vision towards completely transforming into a utility providing company where the product car is completely transformed into a public utility or a standardized service offering like "transportation". Such a vision statement may as well refer to concrete characteristics of a future product or service offering like self-driving car" or a future manufacturing system that autonomously schedules production orders and orders required materials based on actual and future customer demand.

3.2 Stage 2: Enable

The "Enable" stage is dedicated to break down the long-term Industry 4.0 vision into a more concrete business model and to develop principal strategies towards its successful implementation [17], [18]. Strategies answer the question of what has to be done to achieve the desired outcome.

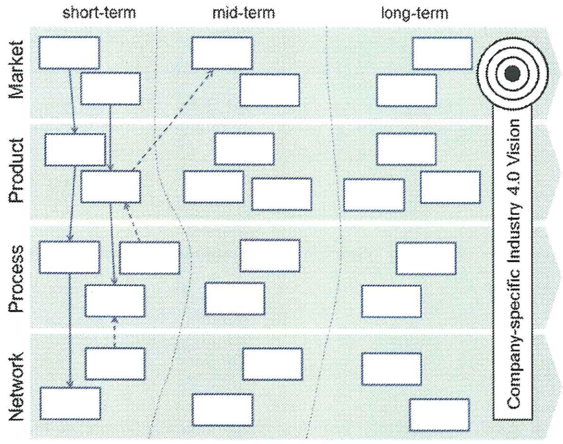

Figure 3 - Exemplary Industry 4.0 Roadmap

To facilitate the strategy planning and alignment process we use roadmapping as a technique for visualization and structuring of strategies (see Figure 3). Roadmapping allows sketching strategies and external constraints on separate layers against a common timeline. For our purpose we use a distinction into four strategic perspectives: market, product, process, and value network. These perspectives are represented by four layers. These layers constitute the vertical dimension of the roadmap whereas the horizontal dimension reflects the timeline.

Each layer is basically used to sketch the expected development of a related perspective:

- the customer segments (the market perspective),
- the value proposition (the product perspective),
- the key resources, technology and activities (the process perspective)
- and the necessary partners (the network perspective) needed to fulfill the value proposition.

The mapping of dimensions is performed in a top down fashion, starting from the market perspective where prospective customer segments are identified thus indicating the principal development of future demand characteristics, e.g. that a customer segment is expected to emerge that no longer owns cars but buys a transport service from A to B instead. From this future market developments product features, products or product lines are derived. The products identified lead to the processes needed to develop and manufacture them.

The process perspective therefore relates strongly to questions of which manufacturing and information technology is required for a future competitive production system. With regard to Industry 4.0, the product and process perspectives are essential as they offer guidance in terms of which technological trends to follow and subsequently what substantial investments to take. E.g. investment in software patents that enable geo-tracking of self-driving cars.

Finally, the network layer shows the necessary structure and characteristics of a future value network that is capable of delivering the intended value proposition. A company may sketch which processes they plan to outsource to which business partners and which other players will have an influence on the process. E.g. a car manufacturer that will need a strong partner in embedded systems development.

Each box in the roadmap represents a state or goal on the way to the ultimate Industry 4.0 vision. Additionally as well a strategy to reach the goal is formulated within the box. Solid arrows represent requirements from the upper to the lower layer whereas dashed arrows represent potential enablers or success factors for the upper layer. The time dimension is indicated by a rough time-frame or a concrete date depending on the overall time horizon of the company.

The output of this stage is a timely ordered and multi-perspective map of the overall strategy towards the envisaged Industry 4.0 vision that builds the strategic frame for concrete actions. The time horizon for realization of the Industry 4.0 vision determines whether a company takes a revolutionary approach versus an evolutionary approach.

3.3 Stage 3: Enact

Finally, the "Enact" stage has the goal of transforming strategies into concrete projects. Thus, project goals, teams and principal milestones have to be defined. Projects are subsequently evaluated and prioritized against the resources available, potential risks and expected impact on the overall mission.

During this stage also projects are included which are currently in progress or under consideration. E.g. a car manufacturer has already launched a project to manufacture electric cars. They are checked whether and how they relate to the newly ideated projects and how they fit into the strategic roadmap resulting from the "Enable" stage. This activity is again conducted in a collaborative manner. Hence, external stakeholders are only involved as far as cooperation is required. Current projects that are considered of relevance for a future Industry 4.0 roadmap are selected and presented by the responsible departments to other stakeholders of the transformation process.

For all projects responsible departments are encouraged to make suggestions about the future integration of the project into the overall strategy and which additional resources are required to fulfill these goals. Projects considered for future inclusion in the roadmap can be both technology oriented projects, organizational change and strategic projects. Alignment of future Industry 4.0 projects with current projects and vice-versa ensures an efficient and sustainable transformation of resources, responsibilities and mindsets in the sense of the Industry 4.0 vision.

The output of this stage – the project roadmap – is finally linked with the previously developed high-level strategies and therefore complements the yet abstract strategic business model perspective with a concrete map of planned activities that can be communicated among principal stakeholders and the wider community.

3.4 Summary

Our process model suggests three stages to develop a company-specific strategic roadmap towards Industry 4.0. It enables a company to clearly communicate its Industry 4.0 vision and strategy internally but also externally towards important stakeholders.

The co-innovation approach along with a systematic visualization of goals, strategies and concrete projects ensures a shared understanding of Industry 4.0, the impact on the company's structure and processes and the required activities to transform into an Industry 4.0 ready company.

The strategic roadmap is regarded as the central artifact that serves three main purposes:

- As a means to consistently analyze and plan the transformation of business models and assess the impact of technology
- As a means to facilitate collaborative development of vision, strategy and projects
- As a tool to manage and track all activities regarding the transformation process towards Industry 4.0

4 FIRST EXPERIENCES FROM THE FIELD

Our three-stage model is the result of a series of workshop sessions that we conducted in the course of an Industry 4.0 initiative which started off in early 2014 in cooperation with Austrian government and several leading industrial companies and associations. Since that we used the model as a guiding framework for raising awareness of the Industry 4.0 vision in the Austrian industrial sector and to guide companies in their first steps towards preparing for a respective transformation.

Our findings show that developing an Industry 4.0 vision is still a challenging task. Although many executives are aware of the potential of Industry 4.0 related business models and technology they had substantial problems to go a step further and develop their own company-specific vision. Rather they had the expectation that Industry 4.0 is the solution itself. However, our co-innovation approach (→ "Envision") shows that rethinking business models by involving multiple stakeholders is beneficial for a mutual understanding of different developments within and beyond the company's boundaries and led to a commitment for Industry 4.0 to be of strategic importance for the whole company and not only for the production department.

Regarding the phenomenon that companies tend to think Industry 4.0 in terms of technology not and rethinking their business models we addressed this misconception through our strategic roadmapping approach (→ "Enable"). Roadmapping encouraged taking different perspectives during the Industry 4.0 strategy development process and therefore also stimulated a discussion about business models.

The mapping of concrete action points or projects (→ "Enact") against the rather abstract strategy roadmap is the point where the maximum of participation was reached. Within this stage middle management and people from operations got engaged as they were able to present current efforts and as well had the opportunity to present their view. In retrospective, we consider the latter stage the most important one as at this point the entire Industry 4.0 vision and strategy will be validated and, in case it is not well conceived or communicated, will fail.

5 CONCLUSIONS

In this paper we describe a three-stage process model to guide manufacturing companies in transforming into an Industry 4.0 ready company. The process model is based on the concepts of co-innovation and strategic roadmapping and offers a guiding framework for the systematic transformation of a company's vision and strategy towards Industry 4.0 readiness.

The process model is unique as it goes beyond a pure technological view and proposes that the fourth industrial revolution needs a systematic integration of generic Industry 4.0 concepts with company specific vision and strategies as a basis for a subsequent technological transformation of the production system. Our approach extends previous research from Fraunhofer (see [8], p. 588) as it provides a solid methodological foundation for guiding companies in their Industry 4.0 related activities.

Although we have developed the process model on the basis of practical experiences we plan to validate and refine our model through further case-studies in manufacturing companies. In fact, the vision of Industry 4.0 is already on the agenda of most industrial enterprises. Hence, our experiences show a strong interest in methodological support to effectively adopt related concepts.

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