Design of a conceptual model for manufacturing companies within the 4th industrial revolution applying the Viable System model

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Abstract: The initiative created under the name “Industry 4.0” in 2011 [3] can help to strengthen the competitiveness of those manufacturing companies [4] able to adapt themselves to this fourth wave of technological advancement driven by various technological advances [5]. Most manufacturing companies have developed departments and initiated projects around the concept Industry 4.0. However, many of them lack the purpose, the organizational acceptance, and the alignment of those activities with the organization’s strategy. Therefore, the aim of this research is to design a conceptual model for improving organizational capabilities thanks to industry 4.0. For this development, the Viable System Model (VSM) was selected as methodological approach. The conceptual model determines the relations between technical areas, technologies, and organizational strategy. The model for Industry 4.0 can help manufacturing companies serving as a guidance for future organizational structure, projects, and activities selection as well as to determine areas with higher potentials according to the status of its technologies and their related current and future capabilities.

Keywords: Manufacturing, Industry 4.0, Viable system model, Technologies, Organizational capabilities.

1. Introduction
The globalization and the increase of virtualisation of business relationships have significantly extended the complexity of the logistics challenge since the 1980s [1]. Global logistics flows have increased drastically in recent years due to a globalized world economy that introduces inherent challenges for establishing international businesses [2]. In this international competition, the compliance to service level in terms of delivery date, delivery reliability and delivery nature is more evident adding more pressure on supply flexibility [3]. At the same time, many producers are confronted with lack of transparency and a volatile behaviour in demand that causes large deviations in sales forecasts [4]. The reasons are mainly the great variability of end customers caused by competitive activities. Other factors that generate effects of uncertainty in planning within the supply chain are, for example, minimum quantities in production, as well as deviations in supply and delivery times that make production planning more difficult, reducing the quality of the production planning [5].

The trends shown lead us in their sum to an increase in the complexity of relationships and processes [6]. In addition, disasters, and pandemics such as COVID 19 (Coronavirus) affect business operations
worldwide creating disruptions that compromise global economy [7]. In this context, manufacturing organizations are facing challenging moments in which organizational capabilities must evolve to remain competitive and secure long-term sustainability. To pursue this goal, the initiative created under the name “Industry 4.0” in 2011 [8] can help to strengthen the competitiveness of those manufacturing companies [9] able to adapt themselves to this fourth wave of technological advancement driven by various technological advances [10]. For a successful implementation of the Industry 4.0 transformation, three core and nine core technologies are required [9]. Most of these technologies are not recent innovations. However, it is the combination of technologies, business processes and data processing that makes Industry 4.0 a novelty [11]. Industry 4.0 pursues rapid product development and a flexible and intelligent production system capable of dealing with greater complexity in products, processes and environments trying to respond to the growing demand for customized products with decreasing product life cycles [12].

Most manufacturing companies have developed departments and initiated projects around the concept Industry 4.0. However, many of them lack the purpose, the organizational acceptance, and the alignment of those activities with the organization’s strategy. Therefore, the fourth industrial revolution is not reaching its potential in those manufacturing companies. Then, the topic continues creating opportunities to acquire competitive advantages. Consequently, final purpose of the paper is to develop a conceptual model how to interact with the environment related to industry 4.0 to develop organizational capabilities that secure long-term viability.

2. Methodology
The methodology starts with the literature review of manufacturing challenges, organizational capabilities, and Industry 4.0. Then, the term and latest advances of “industry 4.0” are described. Later, a conceptual model for improving organizational capabilities thanks to industry 4.0 is developed. For this development, the VSM was selected as methodological approach. The VSM is a cybernetic management model that was developed by Stafford Beer [13]. The VSM is a reference model applied for the description, diagnosis, and design of management models in organizations [14]. As described in the literature, the VSM is a methodological tool for the modelling and design of organizations and its areas with the goal of being viable [13]. Later, based on the conceptual model the relations between technical areas, technologies and organizational strategy are determined pursuing a coordinated set of functions. Then, a guide how to apply the model is generated. Finally, the conclusions are described and future potential research areas for further analysis are derived.

2.1. Challenges of manufacturing companies
Across all industries, companies find themselves in an environment with increasing competitive pressure [15]. The main factors that lead to this situation are the increasing globalization and the resulting competitive situation that causes an intense reduction of the life cycles of the products as well as an
increasing individualization of the final products according to the specific criteria of clients [16]. This evolution is coupled with the demands of customers who want to be served with shorter delivery times [17] as well as with more variants in the manufacturing and assembly processes that expose planning and control processes to new challenges [15]. The consequences of these trends, such as market fluctuations, have a lasting effect in different areas of the company, such as in production logistics as well as in supply and distribution logistics [15, 18]. The challenges of manufacturing organizations are shown in figure 1 and their three areas can be seen in figure 2.

The consequences for trade between companies of the financial and economic crisis are observable today which cause a growing demand for flexibility and adaptability of companies [19]. The reduction of international trade barriers requires intense global cooperation as well as an increase in business complexity [20]. Furthermore, epidemics as COVID 19 and the proliferation of natural disasters and their consequences are an additional source of uncertainty in many industries [21]. Consequently, sustainability and energy efficiency aspects have gained importance. In this context, companies are increasingly obliged to carry out individualized and flexible logistics planning and control [18]. The current global situation increases the exposure of organisations to their related environment, their supply chains, and the dynamics of their internal functional structures.

Therefore, companies must consider a variety of fields that they had managed to a limited extent before. For this purpose, they must operate within a globalized market with multinationals in most industries with the goal of being sustainable. Moreover, there are challenges in the management of external relationships as well as of the management of internal ones [25]. The organisational structure of many companies is highly function-driven that does not give the optimum for the entire process [26].

2.2. The industrial revolutions and the fourth industrial revolution technologies

In the 18th century, the first industrial revolution was initiated, usually described by the mechanisation based on the replacement of human or animal muscle power or the air and waterpower by the steam engine [27, 28]. Then, at the end of the 19th century the second industrial revolution emerged, linked to the increasing rationalization and division of labour in manufacturing companies leading to mass production based on Taylorism [28]. Moreover, the electrical energy was made usable and applied in many new fields enabling a rapid development of production [28]. Later, in the 50s and 60s of the 20th century, the third industrial revolution brought the increase of productivity based mainly on advanced electronics that increased calculation and storage capacities as well as with micro-electronics that increase the possibilities for automation of production processes [28, 29]. In the decades after the 1970s, industrial technological advancements were only incremental or evolutionary [30]. Then, in the 1990s, the lean production vision raised after the successful Toyota production principle. As a result, Lean Production, as a revolution in the organization, was the central production paradigm for the next two decades [28].

In the 2000s, the increasing unpredictability and volatility of the markets as well as a sharp increase in product variance with simultaneously decreasing quantities confront companies with new challenges
that cannot be met with the rigid automation concepts from the third industrial revolution. Worldwide value networks also require an exchange of information along the entire value chain and more intensive cooperation [28]. In this context, Germany started considering plans to maintain and even strengthen its global position as a “forerunner” in the industrial sector. In this context, the term Industry 4.0 was first announced at the Hanover Trade Fair in 2011, as part of the Germany’s high-tech strategy [31]. It was the first time an industrial revolution was predicted a-priori in which organizations can decide how they transform their businesses as it exists the opportunity to achieve excellence in operational effectiveness as well as to develop new business models, services, and products [32]. To reach the revolution in our production systems, a set of evolutionary steps must be implemented and not as a consequence of a single innovation [30]. Therefore, several technologies enable the development of the production system for a successful Industry 4.0 transformation, however the literature review provides no universally accepted definition of Industry 4.0, as well as it provides different sets of drivers, pillars, and enabling technologies [9, 33-35]. Although, this fact is a reality, it can be determined common elements and enabling technologies [35]. From those, this research paper considers three core and nine fundamental technologies [9], for which their main capabilities per enabling technology can be stated in a generic way applicable for managing production and maintenance management within manufacturing organizations [30].

3. Design of a conceptual model for manufacturing companies within the 4th industrial revolution applying the Viable System model

3.1. Conceptual framework

When a manufacturing organization is considered, it can be viewed as an entity with a certain set of capabilities that enable it to perform various activities leading to a market position and as a consequence as an agent interacting with its area of influence. In this context, the organization is confronted with a group of current challenges that are managed with the actual organizational capabilities. In addition, those capabilities can be enhanced by using existing technologies as well as new technologies.

However, the successful management of current challenges and integration of technologies does not necessary lead to ensure viability over time. A manufacturing organization must foresee future challenges and make use of existing and future technologies to secure company’s sustainability. Therefore, future challenges determine which target organizational capabilities will be needed for adapting an organization to them. Based on the target capabilities, future technologies contributing to reach them can be researched and developed. As a result, a technological strategy formulation can be derived aligned with the business strategy. Finally, the transformation from actual to future organizational states can be initiated with their related roadmaps. The framework is shown in figure 3:

![Figure 3. Steps from actual to target organizational capabilities (own elaboration).](image-url)
The above-mentioned steps are to be performed in an iterative manner to ensure the alignment of environment challenges, business strategy, organizational capabilities, and the technological strategy and their related activities. Furthermore, the technological strategy can be push-oriented i.e. technology-oriented or pull-oriented i.e. need-oriented, an organizational need based on a market need. Moreover, the strategy proposed by the conceptual framework is a hybrid push-pull model as shown in figure 4 where there is a determined market need as a challenge for an organization that is specified in a certain detail grade. Based on it, a prediction of the future market need and required capabilities can be defined to develop technologies. The certainty level of the future market need, as well as the actual development phase of a technology determine where the push-pull boundary of the hybrid push-pull approach is set:

![Figure 4. Technological Strategy: The Push-Pull Boundary (own elaboration).](image)

### 3.2. Development a Manufacturing organization applying the Viable System Model

Beer deduced the VSM to deal with complex systems as it is built on three main principles: viability, recursivity and autonomy [15]. The cybernetic model of every viable system consists always in a structure with five necessary and sufficient subsystems [13]. As a result, it matches perfectly the methodological requirements set in the conceptual framework of the model. Based on the VSM, the conceptual model for an organization is developed as shown in Figure 5, in which the recursion level in focus is an organization in its network level where the different plants are the operative systems coordinated, audited, managed and control by other systems. Moreover, the strategic system takes in consideration the external and internal environments to decide on the organization’s strategy to follow:

![Figure 5. Manufacturing Organization applying the VSM (own elaboration).](image)

### 3.3. Design of an Industry 4.0 conceptual model applying the Viable System model

The conceptual model for a manufacturing company for Industry 4.0, consists of twelve technologies as
operative systems, in which there are technology experts within the organization for each of the technologies. The operative units consist of a steering position and a division. The steering position manages the division of each technology as part of the higher corporate policy. The divisions are areas within the organization that act with a certain level of autonomy developing technologies and implementing it in different areas of the organization and that are always in relation with the latest advances for the technology related to the division. System two deals with the coordination of the different operative systems when developing technological solutions that need the effort of various technologies. Moreover, system three plans and controls the development of the activities, while auditing, monitoring, and identifying deviations within and among them. In addition, the internal technological activities are always in communication with the strategic system. It provides the latest status of the Industry’s 4.0 environment as well as formulate the technological strategy for the company based on the technological future requirements aligned with the business strategy and under the Industry 4.0 policy of the organization. The conceptual model is depicted in Figure 6:

![Figure 6](image.png)

**Figure 6.** Model for the introduction of Industry 4.0 technological advances in manufacturing organizations thanks to the VSM (own elaboration).

4. Applying the Conceptual Model and Discussion

4.1. Applying the conceptual model for an organization

To apply the conceptual model for a manufacturing organization, the different technologies should be analysed for each potential area of application. These areas can be broken down into organizational, management systems as well as technical areas. As a result, the steps for applying the model can be defined as a guide. First, it is to define the status of each technology for each potential area. Therefore, it is determined the maturity level for each pair. Moreover, based on the business strategy, the vision for
future capabilities is set as well as the capabilities needed. Finally, a roadmap for each pair can be derived and a prioritization between projects can take place to optimize resources.

4.2. Discussion
Based on the developed conceptual model, an organization must decide on its technological strategy in four areas: focus, internal scope, organizational structure, and know-how strategy:

For its focus:

• whether to generate steering positions and divisions for each technology,
• or to focus on a certain set of technologies,
• or to wait and buy technological advances from the market.

Moreover, a company must decide on its technological internal scope having teams for:

• research, development, implementation, and/or monitoring,
• or perform only some of the previous four activities,
• or to buy all those activities from the market.

In addition, a company decides are how to insert this functional structure within a manufacturing organization:

• it can be under the organizational level or within the functional areas,
• and at network level or at plant level or line level or machine level,
• with operative units working decentralized or centralized.

Finally, the know-how strategy:

• with a centralized or decentralized know-how,
• with higher or lower dependency of know-how from external technology suppliers.

5. Conclusions
After completion of the research work, the following points can be successfully concluded:

• Challenges of manufacturing organizations were described,
• The need for developing organizational capabilities based on Industry 4.0 technologies has been proved as key for long-term viability of manufacturing companies,
• A conceptual model for Industry 4.0 for manufacturing companies was developed. The model contributes to align the technological strategy with the business strategy to face future organization’s challenges,
• A guide was described to develop roadmaps applying Industry 4.0 for organizational, managerial, and technical areas,
• A discussion of the related decisions of the conceptual model for manufacturing companies was stated to help managers to ask themselves main questions when generating their technological and business strategies.

The conceptual model proposes a hybrid push-pull approach for industry 4.0 activities definition. Push-strategy from the new capabilities thanks to the new advances in technologies and a pull-approach derived from the challenges of the technical areas and the strategy-oriented to customers. Moreover, the conceptual model takes into consideration the status of the organization in regard with the activity to be started and with the capability pursued. By implementing the conceptual model, manufacturing
companies can secure that industry 4.0 projects will be aligned with their strategy, with their current possibilities of know-how and initial status, with the current status of the technology as well as with the requirements of the area in which the activity will be developed.

Finally, it is important to point out new ways of research to continue improving the project carried out: improve the conceptual model with an extensive literature review for the different organizational areas, identify the impact of the technological advances, analyse the gap from current status of organizations and the conceptual model as well as searching for specific use cases in each technology.

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