Development of an Intelligent System for Supporting the Sustainable Digital Transformation of the SME Supply Chain

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Abstract. The covid pandemic has disturbed the logistics and industrial organization of companies. In Europe, this specific context, in addition to the war in Ukraine, increases the gasoil price, creating an augmentation of the freight transportation global costs of companies. Industry 4.0 and logistics 4.0 concepts, developed in advanced countries such as USA, Germany, or France, are used with success for improving the company's performance. Despite the benefits of these concepts on the company transformation, numerous brakes exist for their implementation in SMEs. This paper presents a sustainable methodology more adapted for transforming digitally the SME supply chain. Sustainability is used in this methodology as the kernel and is combined with new technologies and organizational methods in the performance improvement. Indeed, an intelligent system is being developed for supporting the methodology implementation in SMES. In this paper, a focus is made on the decision aided module of this intelligent system. After a literature review, the sustainable methodology, and the architecture/development of the intelligent system will be shown. Then, the structure of the decision aided module will be exposed. Finally, an illustration case of SME supply chain digital transformation will be shown.

Keywords: Supply chain performance · Industry 4.0 · Artificial intelligence · Sustainability · Decision aided tool

1 Introduction

The Covid pandemic had a real impact on all countries in the world creating difficult situations in the management of production or on the logistics flows. For European countries, it had shown the lack of production systems, difficulties of procurement, of transport and dispatching. Indeed, due to the working force price, an important part of the production had been delocalized in emerging countries. For being competitive, European companies have to improve their global performance. Industry 4.0 and logistics 4.0 concepts are used for increasing their performance with a great success in large companies. But SMEs are balking to implement these concepts. Brakes that are justified this lack of implementation are numerous, such as the lack of education on new technologies, acceptability of

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new technologies (artificial intelligence, robotics, etc.), the price of new technologies, the fear of job loss, etc. This paper presents a sustainable methodology for transforming digitally the SME performance. Indeed, sustainability is defined as the kernel of this transformation in combination with new technologies and organizational changes. The company performance measure is generally obtained with the triptych QCD (quality, cost and delivery time) in addition to flexibility and reactivity. These key performance criteria will be completed by new technologies measurement and sustainability aspects such as the social, societal and environmental dimensions. Then, this article presents the architecture of an intelligent system being developed for supporting the sustainable methodology and the structure of its decision aided module.

After a review of the literature, the concepts and methodology of the sustainable supply chain 4.0 that have been developed to eliminate non-added value in logistics and production flows will be presented. Then, the architecture of the intelligent supporting the sustainable methodology and the structure of its decision aided module of will be exposed. Finally, an example based on SME supply chain optimization will be proposed to illustrate the concepts presented.

2 Literature Review

This part is focused on the analysis of existing research and studies on Supply Chain 4.0 concepts, sustainability and new technologies. The objective is to find concepts and formalisms that could be used for defining the sustainable methodology for SMEs.

2.1 The Supply Chain 4.0 Context and Sustainability

Digitization allows the collection of massive information to improve the services provided and to offer new services to internal and/or external customers. This is a major challenge for companies because it allows the customer demand to be integrated into the heart of the supply chain. It is a key point of differentiation that also makes it possible to significantly improve the competitiveness of companies. Companies that do not digitize their supply chain may suffer from a lack of competitiveness [1].

Digitalization in supply chain is defined as "a network of interconnected and interdependent organizations that collaborate to control, manage, and improve the flow of materials and information from suppliers to end users" [2]. Companies must therefore create coordination strategies between the various actors constituting the Supply Chain in order to continuously improve their performance over the long term [3], as well as create relationships with their partners in order to strengthen the Supply Chain, but also to promote a sustainable competitive advantage [4]. As explained in [5], the system of sustainable manufacturing transformation includes the use of three axes:

- the economic sustainability supported by the use of lean and six sigma tools,
- the ecological sustainability exploiting the 6Rs,
- and the social sustainability achieved by using seven core subjects, issues of ISO 26000 and social responsibility.

All the optimization processes used therefore aim to maximize and improve customer satisfaction while increasing the profitability and competitiveness of companies.

Several studies carried out previously have underlined that the appearance of Supply Chain 4.0 has simplified the exchange of information flows between the various players in the supply chain, making it possible to better anticipate needs and expectations, in particular thanks to Big Data and to data storage [6]. It has been shown that all information is stored and can be exchanged quickly with the concept of Blockchain, a technology allowing several actors to access the same data from different places [7]. Finally, this situation creates a closer link between the company and the end customer who can now communicate more easily. In addition, the company becomes more efficient and offers superior quality to increase customer satisfaction and improve its performance. Thus, Supply Chain 4.0 offers a competitive advantage since companies can therefore respond more quickly to consumer demands, thanks to an improvement in production processes [8]. Despite, this global benefit of industry 4.0 concepts implementation in supply chain, SMEs are reluctant to use them in their companies. Many brakes have been found and described in [9] and levers have been defined for inciting SMEs to implement industry 4.0 concepts. In this context, a framework has been developed with sustainability as kernel [10] for transforming digitally the SMEs. Indeed, these concepts could be extended to the company supply chain performance improvement by competing them with Supply chain sustainability (SCS). SCS is an approach that takes into consideration environmental (waste, gas emissions…), economic (market competitiveness, transport and financial aspects of the network) and social (health and well-being of workers) of supply chain processes, components, technologies and logistics (Fig. 1.). This SCS approach contributes to define the sustainability parameters for the SME sustainable digital transformation.

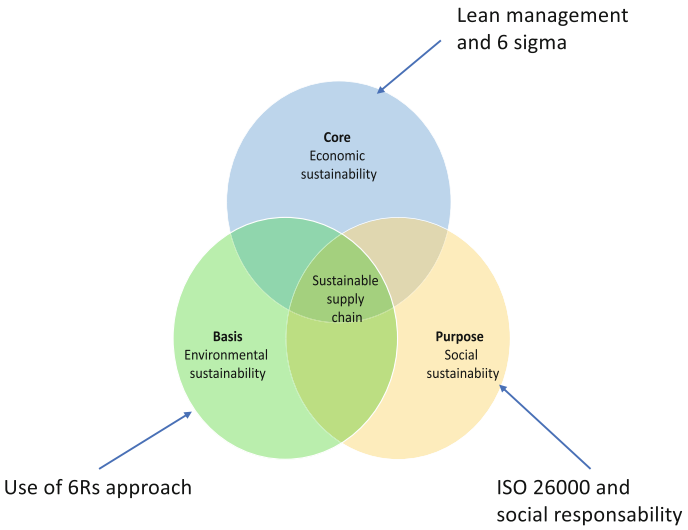

Fig. 1. Relationship between the triple bottom line ad sustainable supply chain

2.2 Organizational Methodologies

Many methodologies could be used for improving company performance, but some of them, such as lean manufacturing, Design of Experiment, DMAIC (Design, Measure, Analyze, Improve and Control) method, and GRAI methodology are particularly adapted to the company digital transformation. A focus is made in this part on lean manufacturing and its tools for explaining how these methodologies could be used. Lean manufacturing is an organizational method for optimizing industrial performance that aims to better meet customer requirements in terms of cost-quality-time. It is a question of analyzing in detail the various stages which constitute the production process then, to hunt all the waste identified throughout the manufacturing process allowing then to be more efficient and more profitable [11].

This methodology was developed in the 1950s from the Toyota Production System (TPS) created by Ohno. The principles of Lean are the quantification of the value in collaboration with the customer, the identification of the value chain by highlighting the level of waste, the creation of a new process flow without non-added values by reducing waste (Mudas) such as stock and work in progress, the pulled flow organization of the value chain with a production guided by customer demand and the process continuous improvement [12]. Various tools have been developed in this context to support the transformation of the company's production according to just in time philosophy such as Kanban to manage the transfer of bins and to optimize the manufacturing processes cycle in addition to the reduction of the tools exchanging time (single minute exchange of die (SMED). The manufacturing processes performance can be measured by using the triptych of cost, quality and lead time (QCD). This production improvement method is constantly evolving and adapting over the decades to the consumption patterns of companies and the new technologies. Thus, tools such as Jidoka, Kaizen, 5S, Value Stream Mapping (VSM) are also used in the company transformation. This methodology integrates many tools and its impacts on the company organizational transformation is important. But other methodologies offer a structure that could be exploited in the frame of the company digital transformation. Indeed, DMAIC method allows to define formalized steps for the problem-solving process that is required in the company digital transformation. A general approach in the company modelling based on existing system modelling, analysis, and the future system elaboration (GRAI methodology) could allow contribute to defining the appropriated concepts for the digital transformation. Finally, design of experiments concepts could also be used for increasing the efficiency of the transformation based on existing data exploitation for formalizing the sustainable digital transformations concepts. Indeed, all the tools presented above will be combined in the methodology part.

2.3 The Supply Chain 4.0 Technologies

The supply chain 4.0 concepts are based on industry 4.0 concepts and all of them such as IoTs, Cyber-physical systems, big data, robotics, augmented reality, digital twins, and artificial intelligence contribute to the company performance improvement. These new technologies are mainly used for transforming digitally the company. Indeed, IoTs

contributes to measure in real time the state of the supply chain. IoTs support the communication tools between smart devices and their interconnections [13]. This system is used for acquiring data on the supply chain. A cyber-physical system is described as "an industrial automation system that integrated information technologies and the physical reality of the business operations with the virtual world [14]". Big data and big data analysis tools are used for storing massive data acquired in the supply chain, treating them and using them for improving the company performance. Indeed, structured and non-structured data are contained in the big data in opposition to data warehouse that contains only structured data. The advantages of big data technology are numerous, such as access to unlimited data network, real times perceptions, ability to measure the company level in comparison to concurrence, etc. [15]. Robots and cobots participate to the repetitive tasks realization and collaborate with the operator in the product elaboration. Digital twins are used as a decision aided tool for transforming virtually the company performance before investing in real components. Immersive realities are exploited for instance to solve maintenance problems. Artificial intelligence is used default detection (machine learning) [16], image recognition, visual programming and treatment (deep learning) [17], digital and decision aided tool development (expert system). New technologies as presented above could be combined with organizational methods, and sustainability could be used as the kernel of the digital transformation method.

3 Methodology

Most of the existing supply chain 4.0 companies focus exclusively on the technological tools but none on the social, societal and environmental dimensions. A combination of both aspects is required to develop the sustainable and efficient Industry 4.0 for SMEs [9]. The extension of this framework is described in the Fig. 2. And is based on the sustainability and new technologies for increasing SME performance. The company sustainable digital transformation is based on three axes: physical, decisional and informational. The physical transformation of a company is done by exploiting organizational methodologies (Lean manufacturing combined with DMAIC and DOE). The decisional transformation of the company is realized by using GRAI methodology. And the informational transformation involves the introduction of new technologies for improving the company performance. This framework is used on SMEs (Small and Medium Enterprise) which are not available for implementing existing industry 4.0 concepts. The idea is to optimize continuously the supply chain performance of this company in a sustainable way. Sustainability is considered as the kernel of the company transformation. Sustainability parameters are social, societal and environmental dimensions and combined with new technologies, flexibility and aspects related to change to increase business performance. A hybrid methodology containing lean manufacturing tools such as VSM (Value stream mapping) has been developed to achieve the transformation and ensure the company performance improvement. The supply chain 4.0 is constantly measured by using the criteria described above (cost, quality, leadtime, social, societal and environmental).

The process is detailed and optimized by leveraging the hybrid methodology with a particular focus on lean manufacturing. The VSM tool is used to find non-added values at each stage of the production processes and to eliminate them. Tools adapted to new

technologies are used for the digital transformation, as shown in the figure below. The operational management of the supply process requires the implementation of an automated storage. Transporting raw materials from storage to production lines requires the use of automatic trains, or AMR. Indeed, the company transformation will be managed by decisions and investments in the short, medium and long term. Due to the amount of data circulating in the company and the consequences of the transformation, it is important to design and develop a data analysis tool and to set up an information system to facilitate the management of the business. Around the philosophy of sustainability, the company's processes will be transformed by exploiting new technologies such as AMR, the stacker crane, monitoring tools, IoT and organizational methods.

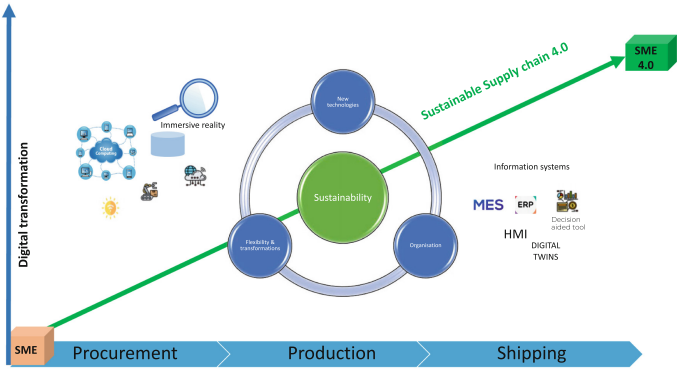

Fig. 2. Sustainable supply chain 4.0 framework

By focusing on sustainability as the kernel of the SME digital transformation, this methodology provides an efficient response to treat brakes of SMEs in the industry 4.0 concepts implementation. This methodology is based on the entire participation of employees at each step of transformation and the integration of their expectation for defining the most adapted new technologies and tools that have to be implemented in the company. Then, this methodology requires the development of an intelligent tool for supporting data and steps of the transformation.

4 The Decision Aided Tool of the Intelligent System

In this part, the architecture of the intelligent system that supports the sustainable digital transformation of the SME supply chain is shown Fig. 3, presents the architecture of this intelligent system.

The **human/machine interface (HMI)** creates interactions between the machines, cobots, robots, the information system and people during the supply chain transformation. The **decision aided tool** is destined to measure and optimize the SME performance through the sustainable and digital transformation. The **modelling module** is used for realizing the modelling of the SME. The **coordination module** is elaborated for managing the modules of the intelligent system. The **expert system** exploits expert rules

for the company digital transformation for analyzing the existing system. The **problem-solving module** is used for finding solutions based of human expertise. The **knowledge capitalization** module contains the old situations that could be reused for transforming the company. The **simulation module** serves to elaborate the company digital twin by exploiting existing simulation tools such as Flexsim, Anylogic and PTV VISSIM. The **scenario builder**, on the base of the digital twin contributes to the test of different situation for finding optimized solutions.

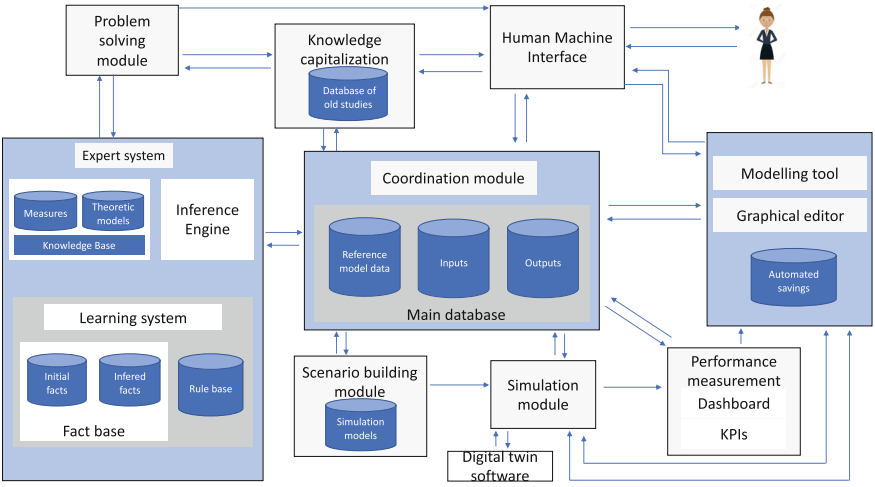

Fig. 3. Architecture of the intelligent system for sustainable supply chain 4.0

In this intelligent system, the decision aided tool has been developed for measuring the company performance at each state of the sustainable digital transformation (Fig. 4).

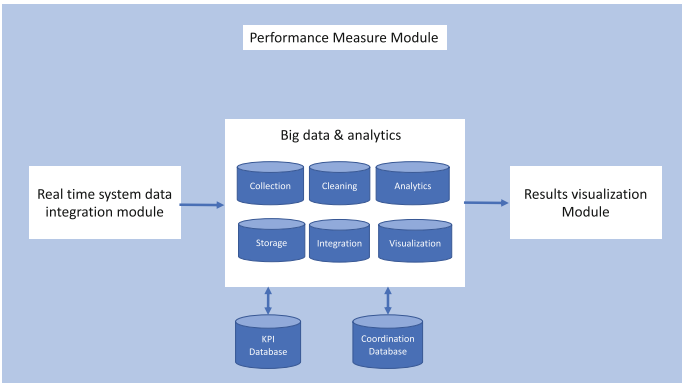

Fig. 4. Performance measurement module

Five criteria have been selected to examine the company performance: sustainability (social, societal and environmental aspects), quality, cost, lead time and modernization degree. Each criterion is divided into sub-criteria, for clearly measure the state of the company according to the chosen criterion. The elaboration of these sub-criteria is based on the use of ISO 50001, 14000, 9000, 26000 standards, for corresponding to company performance real expectations. The decision aided tool is composed of:

- a **dashboard** which presents all data measured to the user through a software module (application) also called the results visualization module and given to the user suggestions for taking the right decision,
- a **calculator** which integrates all algorithms related to sub-criteria and that will be used for measuring the company real time performance
- an **evaluator** which corresponds to a tool including big data and analytics for comparing ideal (reference model), the existing system and to the future proposition measures and provide suggestion of decision that will be presented in the dashboard.

For the **social criterion**, the sub-criteria are quality of life at work, decision-making, autonomy and CSR (company social responsibility) and ISO 26000 standards implementation. The **environmental criterion** is composed of carbon footprint, environmental approach, 6Rs, ISO 50001 standards implementation and ISO 14001 standards implementation. The **quality criterion** integrates the product quality (quality control), the process quality, the system quality, the product traceability with and ISO 9001 standards implementation. The **cost criterion** exploits transport cost, delivery cost, manufacturing cost, storage cost, and procurement cost. The **lead time criterion** contains sub-criteria such as the delivery time, the manufacturing time, storage time, and procurement time. The **modernization degree criterion** is composed of supply chain 4.0 concepts such as internet of things, robotics, information system, cyber-physical system, immersive reality, big data, cloud computing, artificial intelligence, 3D printing and digital twins (Fig. 5.)

	Modernisation		
	Supply chain 4.0		
	Questions	Responses	Quoting
1	are robots or cobots present in the company?		
2	are IoTs or sensors used for collecting data in the company?		
3	Are big data or data warehouse implemented in the company ?		
4	Does the company use immersive realities?		
5	Does the company use cyber-physical system?		
6	Does the company use information system?		
7	Does the company have 3D printing machines?		
8	Does the company elaborate a digital twin?		
9	Does the company have cloud computing ?		
10	Does the company used tools containing artificial intelligence concepts?		
		total	

Fig. 5. Criterion quoting

The performance measure corresponds to a combination of all sub-criteria results.

5 Illustration in SMEs

The decision aided tool has been developed and has been tested on two companies. The first company is specialized in industrial food cooking business and the second Mobile home elaboration. These companies are being Both transformations are being realized. The first step of the study consists in modelling the existing system of both companies. Then, the decision aided tool has been used for supporting the qualitative survey. This tool has been done for measuring the actual (and future) state of each company. For instance, the actual modernization performance of the food company has been elaborated (Fig. 6).

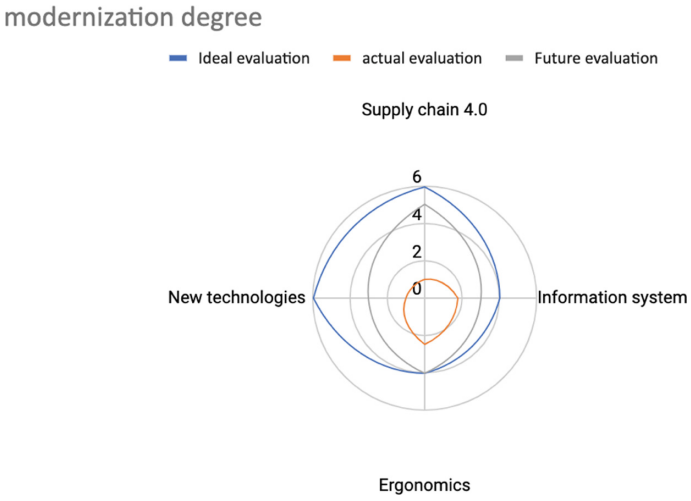

Fig. 6. Modernization maturity measure

This measure concerns sub-criteria such as new technologies, supply chain, information system and ergonomics. Each sub-criterion is also divided into parameters that are measured for obtaining the result presented above. For instance, 9 parameters (IoT, Robotics, etc.) are proposed for the modernization criterion. This structuration has also been realized for the other criteria (cost, quality, lead time, social, societal and environmental aspects) involved the company transformation. These measures have shown that the company needs to be transformed digitally. The performance measurement process is subdivided into several blocks, that allowed to collect information on the company state. Structured and non-structured Data acquired on each company have been exploited for analyzing the company situation. The ideal situation defined in the decision aided module have been exploited for suggesting decisions for the company transformation. For instance, the decision to increase the use of new technologies in collaboration with operators has been taken and use cases on working stations including cobots and operators have been tested. The results allow to validate this human-cobot collaboration. The

next step will be the use of the intelligent system for transforming each company according to the recommendations of the expert system (analysis tool). Indeed, the company digital transformation is ongoing. Then, only partial results allow to deduce the company performance improvement. The presentation of the final results in the future will allow to validate the decision aided tool and the sustainable methodology.

6 Conclusion

This article presents a sustainable methodology based on industry 4.0 and exploiting sustainability as one the main criterion, for transforming digitally SMEs and improving their performance. This methodology corresponds to a response to the SMEs chilliness on the industry 4.0 concepts implementation. The sustainability, as the kernel of the company digital transformation involves the use of Triple Bottom Lines method for defining specific criteria in addition to quality, cost and lead time. The data management, and the processes continuous transformation imply the development of an intelligent system for supporting this sustainable method and increase the transformation efficiency. Indeed, the decision aided module presented in this paper validates the existing and future systems measures and the use of a reference model as an aid in the decision taking process. The research-action method including the use of real cases of companies allows to validate the sustainable methodology efficiency and shows that the new technologies acceptability by SMEs will increase. The intelligent system is being developed and a global study using qualitative and quantitative methods will be used for definitively validate the sustainable methodology and its tool.

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