Methodology Combining Industry 4.0 Technologies and KPI's reliability for Supply Chain performance

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Abstract:

In the context of internationalization, the supply chain is becoming complex with a profusion of decisions to take. The modeling and measurement of supply chain (SC) performance has been widely addressed by researchers, however the arrival of new technologies in the era of industry 4.0 is changing the environment and implicitly impacting the Key Performance Indicators (KPI) for SC management. Although several models exist, none of them is specifically oriented for SC operations management considering the importance of KPI and inclusion of technologies of industry 4.0 concomitantly.
This paper presents a research methodology targeting a reference model to grasp SC state with decisions identification called GRAILOG from which a set of KPI is built to support the different decisions. A methodology called PPTechIP is then described and demonstrated to lead and advise the company on the industry 4.0 transformation relevant to build reliable KPI. PPTechIP is based on a set of radars split into different decision levels and functions of the SC based on GRAILOG model. Potential of Progress is calculated and assist the manger in their decision making. PSA (French Car Manufacturer) embracing the era of industry4.0 was chosen to implement the model. The results, using the suggested methodology, provide several interesting insights in the control indicators of PSA. Big Data, Augmented reality and collaborative robots grasp great attentions from PSA and are judged as prior to continue the follow up and Cloud computing is judged as being an alert, carefulness to over investment has to be considered.

Key words, Supply chain management, Key Performance Indicators, Industry 4.0, Technologies, Automotive industry

1. Introduction

SCs have become weighty with continuous growth and heavy networks including a variety of process to monitor and control (Fawcett and al. 2012). These organizations felt as first challenge the need to optimize the production and speed up the flow while keeping high level of quality rate for the products using Lean implementation methods (Amrani and Ducq 2020). Bring high rate of quality is important and lead the manufacturing rate down by eliminating the waste and non-value added work is recommended (El kihel et al. 2019; Dhiravidamani et al. 2018; Qi et al. 2017). Context importance to deploy the relevant Lean practices in aeronautic SC has been studied and confirmed in (Amrani and Ducq 2020; Possik et al, 2021).
Later, the SC evolved towards other dimensions considering social and environmental perspectives to guarantee efficiency not only from economic perspective but ensuring sustainable organizations and making eco-friendly products (Wang, Zhang and Zhu 2017).
Another important challenge beside the optimization of the flow and sustainability is to embrace the era of industry 4.0 by adopting the relevant and suitable technologies. (Luthra and Mangla 2021) evoke technological challenge as an important dimension. Higher infrastructure and

efficient internet networks are crucial to manage the interconnected devices effectively along the SC. Then, transparency across the supply chain is becoming important (Birkel and Muller 2021).

Arguing necessity of deploying technologies of industry 4.0 is not sufficient to impulse their use. (Onar et al. 2018) suggested that "organizations need to develop their capabilities in terms of workforce expertise, strategic organizational policies, better leadership instruments and friendly business culture to diffuse Industry 4.0 sustainability oriented practices". Authors pointed out the top management importance to involve proactively such transformations. (Hoek 2020 and Xu et al. 2020). (Chamola et al. 2020) claimed that agility and collaboration are powerful enablers to lead 1ndustry 4.0 transformation. Speed and scalability of tools compared to the human workforce have helped firms cope with disruptions (Covid19 examples) in (Bellhadi et al. 2021; Ivanov and Dolgui 2020a). Based on the investigations of (Manavalan and Jayakrishna 2019) the conceptual model outlines the SC challenges structured around *business, technology, sustainable development, collaboration, management strategy perspectives*.

In today's context, if the SC is relevantly facing the new challenges using the technologies, it can completely disrupt traditional execution, by creating a 'smoothly running, self-regulating utility that optimally manages end-to-end workflows and requires very little human intervention (Lyall, Mercier and Gstettner 2018).

So, the objective of this paper is to present a methodology to help companies to detect their weaknesses in the implementation of industry 4.0 technologies. This methodology is based on decision model and KPI's that allow to quantify the needs of industry 4.0 technologies and the current status of implementation.

The paper is structured as follows, the first part presents state of the art on the modeling and monitoring of SC, the Supply chain 4.0 and the link between new technologies and KPI's. Then, the problematic and research questions are defined. A methodology for measuring the potential of progress when leading 4.0 transformation is built. This approach proposes a set of steps that will be described and argued to demonstrate the implementation. Because, the automotive industry is a cornerstone sector to lead industry 4.0 transformation, the connectivity and technological advancements are still pending for many manufacturing organizations, although the automotive sector is ready for the adoption of these technologies (Ghobakhloo 2018). So, finally, the implementation of the PPTechIP model is provided in automotive industry with application in PSA – Moroccan site. The last section evokes the analysis and discussions of the results obtained to guide the decision makers and define the alert points to be controlled for automotive SC.

2. Literature review

2.1 Supply Chain Modeling and Monitoring

Regarding the complexity of the SC and the various aspects that it entails, modelling a supply chain becomes a challenge in the research scope and ambitious task because of the difficulty to be exhaustive to contain all critical points of this sophisticated system. Each author pretending to model the SC will undertake a modelling with its own vision and approach. Indeed, partial model of SC cannot be considered as global model. For instance, in (Rahimi 2020) authors consider the SC from distribution and logistics points of view only. One of the main factors relating the effectiveness of the SC is the rational organization of transportation within the chain through a rational route for goods delivery. Indeed, the objective of a modeling is to describe the existing and the future state of a process and to define the different methods and management solutions to adopt in order to design or control the SC by reaching the best performances. A model of expert system with a fuzzy knowledge conclusion to support decision-making is built by logisticians. But the model is not at all dealing with global SC modelling.

The modeling of the global SC is complex because it is necessary to master the components of the chain and to ensure a modeling that allows the optimization of the processes related to production, supply, storage and distribution. The table 1 below summarizes findings of the different models that were identified for SC modelling and the main aspects considered: Sectors, Processes, decision level, flows, internal, external. Some of them are reference models with the objective to describe a generic unfolding of the SC and other are modelling methods aiming to represent any kind of systems among which SC. The SCOR model is essential in a SC because it allows a visualization by key processes. SCOR, AFNOR, SCM, ASLOG, BSC, GRAI, VRM are also possible models. However, each model considers the SC from a particular point of view, and we would like to analyze the key points and include them in our proposal.

Criteria of comparison		SCOR	AFNOR	SCM	ASLOG	BSC	EVALOG	GRAI	VRM
Sector	Industry						×		
	SME			×					
	All sectors	×	×		×	×		×	×
	Distribution					×			×
Modeling	Process	×			×				×
	Decisional								
	Indicators	×			×				×
Decision level	Strategic level		×	×		×			
	Tactical level	×	×	×	×		×	×	×
	Operational level	×			×		×	×	×
Flows analysed	Physical flow	×	×						
	Information flow	×	×	×	×	×	×	×	×
	Financial flow	×	×		×	×	×		×
Benchmark	Internal	×	×	×	×	×	×		×
	External	×				×	×		

SCOR: Supply Chain Operations Reference
SCM : Supply Chain Master
VRM : Value Chain Group
BSC : Balnced Scorecards
AFNOR: L'Association Française de NORmalisation
EVALOG: EVALOG GLOBAL
GRAI: Graphe à Résultats et Activités Interreliés
ASLOG : Association Française de la Supply Chain et de la logistique

Table 1. Comparison of SCM reference models (El kihel 2021)

To further our study, the authors compared the 8 evaluation models (Table1) this study shows that there are important gaps. Some levers are completely hidden in some models and a little too deep in others. Levers such as the development of a process vision and the lever of indicators are presented in the majority of models, however the "decision-making" vision is not perceptible, or even non-existent. The exception is the GRAI model, considered as important with the process vision and the development of indicators.

For the decision-making levels, the two models VRM and GRAI present a decomposition of processes according to a hierarchical, strategic, tactical and operational approach. The other models are based on a maximum of two decision-making levels. Moreover, concerning the analysis of flows, AFNOR and SCOR characterize the SC by all three flows (physical, information and financial). The rest of the models deal with only two flows (information and financial) as in the VRM, ASLOG and BSC models. At the benchmark level, the majority of performance evaluation models such as SCOR, EVALOG and BSC are also internal and external benchmarking tools that aim to be inspired by the best practices and align themselves with the best companies.

2.2 Supply Chain and industry 4.0

Linking Industry 4.0 and SC is grasping research attention. Industry 4.0 enables companies to boost economic values, such as their competitiveness, productivity, and especially revenue growth (Bonilla et al. 2018). The management of the SC can be based on models, standards and new technologies to support the strength of KPI. This section will detail the interest of Industry 4.0 in reinforcing SC management and will discuss it as a means of contributing to its evolution and optimization. Digital supply chain can be defined (Ageron, Bentahar and Gunasekaran 2020) as the development of information systems and the adoption of innovative technologies strengthening the integration and the agility of the supply chain and thus improving customer service and sustainable performance of the organisation. The industrial production systems are expected to perform 30% faster and 25% more efficient if leading Industry 4.0 transformation (Rügmann et al. 2015).

In the era of industry 4.0, traditional SC has a great potential to turn to a highly efficient digital SC by smartly connecting product development, procurement, manufacturing, logistics, suppliers, customers and service (Brettel et al. 2014). With focusing on production aspect, the lndustry 4.0 enables real-time monitoring and controlling of important production parameters, such as production status, energy consumption, flow of materials, customers' orders, and suppliers' data (de Sousa 2018; jabbour et al. 2018b). Interconnecting machines that enables making customized products ensures flexibility and intelligent machines management (Lasi et al. 2014).

Beyond production aspects, the logistics part is capital. The logistics operations are a key function where asset tracking or in-transit components are complex. IoT can help in monitoring the logistics operation (Qu et al. 2017). (Rahimi 2020) reminds that the field of logistics is widely welcome application in logistics digitalization systems, industrial IoT and BlockChain.

Various scholars are convinced that SC resilience can be supported by technologies as big data analytics, IoT/IA, and call for research in this area (Birkel & Hartnlann 2020 ; Dolgui & Ivanov 2020). SC resilience has been proven to be improved (Spiesk and Birkel 2020) thanks to Big data to adopt in priority while other technologies as additive manufacturing and cyber-physical systems, still lack proof of effectiveness.

(Kumar et al. 2020), suggests four categories to consider when introducing industry 4.0 technologies as support for SC, namely Technological, Economical, Socio-Economical and Social categories. These challenges were analysed and resulted into 'Lack of IT infrastructure' as the most influential barrier preventing I4.0 implementation in manufacturing organization. It was found in (Hopkins 2021) that larger firms were better prepared for technology adoption than smaller firms. This finding subscribes to previous research findings highlighting the size as a factor for technology adoption rates (Palvia et al. 1994; Premkumar and Roberts 1999).

To get an overview of the common technologies used in the automotive industry, a literature review is performed with a sample of 1887 documents (publications, books and magazines) Scopus source. To perceive the most used technologies in Industry4.0 transformation, the following extraction from scientific articles was performed. As shown in the figure.1 on the left, the result entails IOT, IA and BIG DATA as the most frequent quoted technologies. The sample on the right of figure 1 concerns only the scientific publications, for which the analysis mentions IOT, 3D and IA as being the most published subjects for time window (2015-2020).

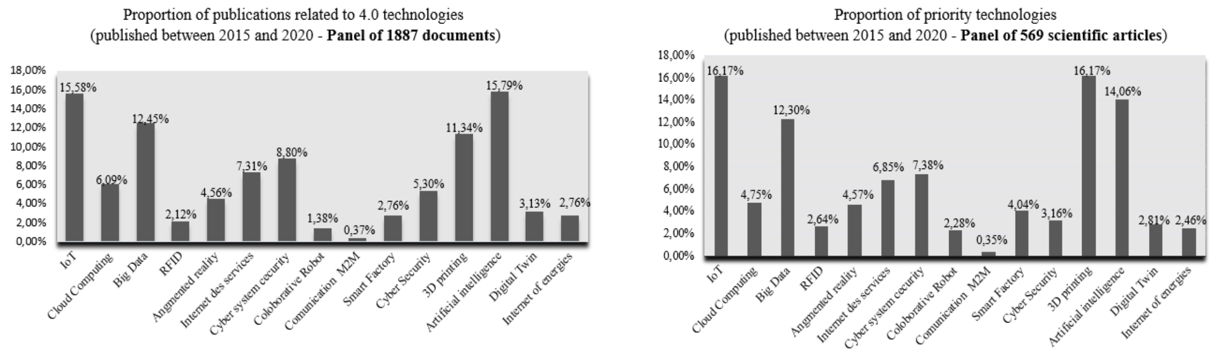

Figure.1 The proportion of the used Technologies of industry 4.0
(Sample analysis (n =1887), (m =569)

(Gamache 2019) examined a survey of 51 publications to highlight the tools most frequently associated with Industry 4.0 such as Big data, Smart factory, Smart factory, Cloud computing, Internet of things, M2M, The internet of things.

(Saturno et al. 2017), presents the technological pillars RFID, Cybersecurity, Cloud Computing, Mobile technologies, Machine To Machine, 3D Printing, Advanced Robotics, Big Data/Analytics and Internet of Things that transform production systems from Automated to Autonomous/Intelligent (Cyber Physical Systems). The pillars are also confirmed by Culot et al.'s (2020) review of Industry 4.0 definitions, as well as other Industry 4.0 reviews (Sanchez et al. 2020; Ciano et al. 2020 ;Calabrese et al. 2020 ; Liao et al. 2017; Parente et al. 2020 ; Machado, Winroth and Ribeiro da Silva 2020).

In order to select the most relevant qualifying technologies, those most frequently cited in the literature were considered to support our work. The previous analysis and references dealing with these comparisons allowed to consolidate the interest and use of technologies in the automotive industry. At this point it is then possible to generate the list of qualifying enabling technologies most relevant to our study. A list of 12 most relevant technology groups (also given in the Boston Consulting Group, used in (Jovanovski and Joanneum 2019; Rüβmann et al. 2015) are retained : *Big Data / Artificial Intelligence, RFID, Digital Twin, Cloud Computing, Augmented & Virtual Reality, Cyber Security, Internet of Things (IoT), Smart Grids, Collaborative Robots, Additive Manufacturing and 3D Printing, Machine Learning, Simulation.*

2.3 Technologies of industry 4.0 and KPI

Several works have been identified on the relationship between new Industry 4.0 technologies and specific SC characteristics such as the resilience (Spieske & Birkel, 2021) and sustainability (Bag et al. 2018) . Another study highlighted the relationship between I4.0 technologies and Lean Supply Chain (LSC) strategy (Nounou, Jaber and Aydin 2022; Núñez-Merino et al., 2020). On the other hand, the contribution of technology and the study of the relationship with KPIs is little addressed in recent years, though these KPIs are important measures of progress (Felsberger et al., 2022). (Dubey et al. 2018; Dubey et al. 2019) point out that new technologies can significantly impact indicators such as agility, alignment, adaptability and their effect on performance in SC. (Jede and Teuteberg 2015); (Giannakis 2019) and (Gunasekaran et al. 2017) have explored how cloud computing, Big Data, and predictive maintenance can improve SC performance indicators especially robustness visibility, resilience and organizational performance. One of the main reasons manufacturers are adopting I4.0 technologies, such as cyber-physical systems (CPS), the Internet of Things (IoT), artificial intelligence (AI), or Big data, is to increase efficiency and productivity through smart and remote management (Hohmann and Posselt 2019 ; Da Silva et al. 2020).

(Buer, Strandhagen and Chan 2018) have pointed out that Industry 4.0 technologies can boost lean practices, such as factory integration, IoT, and sensors can improve Kanban and shorten cycle time (Hofmann and Rüsch 2017).
Indeed, the development of SC can integrate innovative technologies such as Blockchain, augmented reality and Big Data. These technologies improve KPI's regarding intra and inter-organizational costs and create more value for companies (Ageron, Bentahar and Gunasekaran 2020). Industry 4.0 technologies such as cloud computing, additive manufacturing, Internet of Things, blockchain, data analytics, artificial intelligence and edge computing are enabling greater flexibility and adaptability to SC networks (Choi et al. 2022 ; Ivanov et al. 2021b ; Cai et al. 2021 ; Dubey et al.2021 ; Ruel et al. 2021; Zheng et al. 2021; Kusiak 2020).
Many researchers linked the industry 4.0 technologies to performance as: visibility improvement, resilience, productivity, flexibility, adaptability without clear identification and accurate association among technology and its KPI. Few works have been identified proposing specified dimension of KPI. For instance, (Mrabti, Hamani and Delahoche 2020) looked at logistics 4.0 through an illustrative example. These authors demonstrated that better results were obtained by evaluating economic KPI's (vehicle fill rate transport cost, loading cost and unloading cost) and environmental KPI's in the form of CO_2 emissions. Amazon has used Big Data analytics for pre-shipping prediction of products to distribution sites near customers before orders are placed (Ardito et al. 2019; Lee 2017). The goal is to establish indicators to anticipate demand while increasing product availability and ultimately make the company's SC's more agile.
Regarding the browsed literature, no structured and dedicated method targeting accurate and concomitant identification of industry 4.0 technologies with several KPI's for supply chain management were found to provide a guideline and roadmap to sustain SC manager's decisions. The proposed methodology subscribes to this gap and demonstrates along the coming sections the steps necessary to disclose the efficiency of KPI through the introduction of Industry 4.0 technologies.
The target is to provide the practitioners and managers with a model to monitor and control the decisions of the SC by the introduction of technologies to support the KPIs for SC management. The authors will discuss the interest of new 4.0 technologies in the reliability of KPIs disclosing several steps of the suggested model.

3 Problem statement

Currently, it is difficult for companies to choose the most appropriate technologies for their needs. In the literature mentioned above there are several studies of the impact of Industry 4.0 on SC performance, but rare are the studies depicting the impact of Industry 4.0 in the management and monitoring of SC through well identified indicators with accurate analysis. Often, companies try to optimize only a part of their SC and this for various reasons, by lack of hindsight, lack of knowledge, lack of tools and models allowing them to approach the SC in its entirety. Very often, the optimization concerns one department disregarding others (primarily the production to the detriment of maintenance and quality as stated in (Lyonnet 2010). Some studies focus on the optimization of downstream logistics in order to guarantee optimal vehicle rounds (Rahimi 2020) and to supply delivery points. Others focus on making production more reliable by ensuring the reliability of suppliers and this supply process then becomes a priority.

The challenge of the methodology targeted in this paper is to link concomitantly: SC processes, decision-making levels, Industry 4.0 technologies, KPI and to act on all of them in a unique and coherent approach. Companies are integrating and investing in new digital technologies, however, no visibility of the interest and connection between these 4.0 technologies and critical SC decisions with visible impact on KPIs is highlighted in a well structured, demonstrated and common approach. To tackle the explained problematic, the following research questions are addressed:

Q.1 How to model a SC taking into account its multiple dimensions: multi-stakeholders, multi decision-making levels, multiple activities, multiple processes?

Q.2 How to provide a structured, step-by-step approach within global Supply chain framework for monitoring the reliability of KPIs in relation to the 4.0 technologies in order to invest on?

4 PPTechIP Methodology

The addressed research questions above remind the importance to consider multi-factors problem of SC Management associated with performance evaluation and KPI monitoring. The suggested methodology, proposes to start building a model of SC, followed by an analysis of technologies contribution to various decisions, functions and KPIs. Visualizing the impact of technologies in the decision making process encompassing the possibility to perceive the progress axes that appear helpful for decision makers to orient their choice accordingly. The KPIs supported by Industry 4.0 technologies thus may become smarter, more reliable and increased in their potential. The next part presents the methodology with detailing each step.

4.1 PPTechIP : Potential of Progress in Technologies of industry 4.0 for smarter IP

The figure 2 belows presents all the steps of the PPTechIP methodology « **P**otential **of P**rogress **of Tech**nologies 4.0 for smarter **I**ndicator of **P**erformance **»** to make indicators more reliable, more intelligent and more relevant for a SC.

A set of 12 technologies, chosen regarding literature review, are kept for this study. The target is to monitor the progress of implementation of each one of the pre-selected technologies of industry 4.0. Obviously the set is not limited nor locked; if any company would like to study the impact of new technology, it is possible to include and update the model.

The proposed GRAILOG model is useful to represent the typical decisions required to control the exploitation of the SC. Within each function and decision, a set of KPIs (strategic, tactical and operational) has been defined and analyzed. At this point of the methodology, it is possible for a company to measure its current state of advancement in I4.0 technologies on a value scale proposed by a chosen maturity model. A grid of KPI associated to GRAILOG is obtained.

The last phase of the methodology (after GRAILOG, Grid KPI) is to evaluate the relevancy of the technologies with SC KPI.

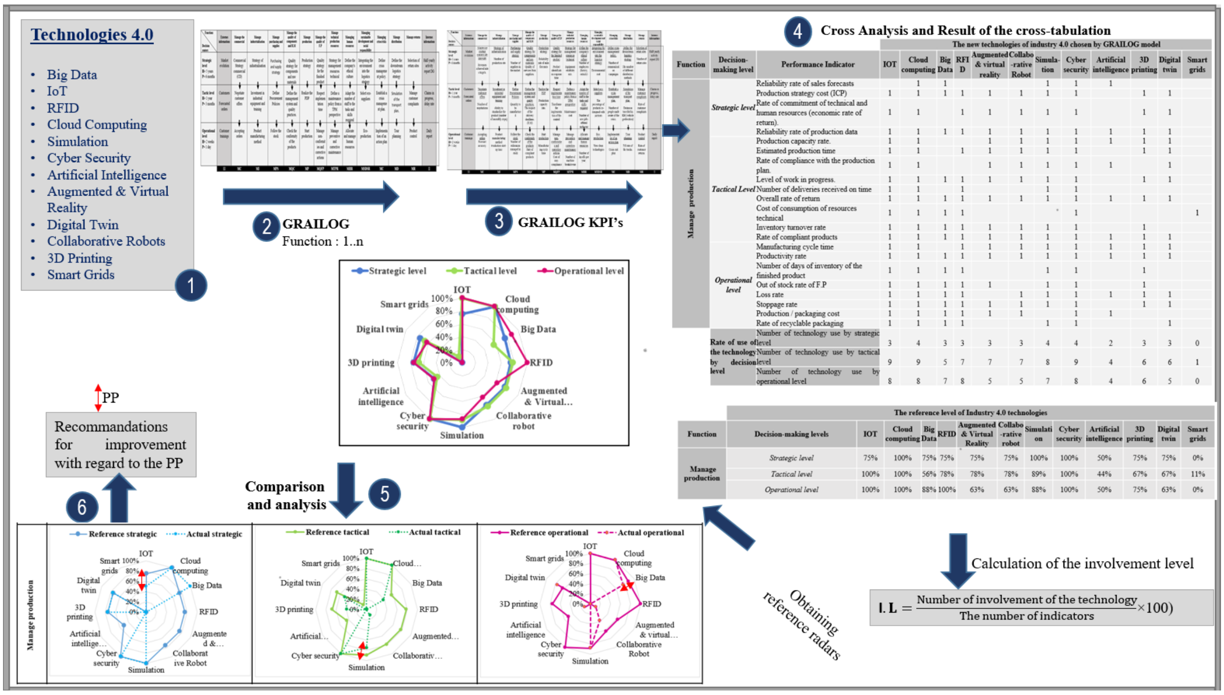

Figure 2. PPTechIP methodology: Steps and expected results

PPTechIP consists on a cross analysis combining the technology impact on each KPIs considered in each of the SC functions and at different levels. The considered hypothesis subsequent to PPTechIP is that: « *Some technologies of the industry 4.0 are more adapted to the construction, the reliability and the smartization of certain KPIs than others* ». Then, a baseline of technologies usage is identified by a radar representation. The last part is a comparison that will be conducted to measure the difference between the expected level and the realized level of technologies I4.0 in the company. The « potential of progress » that the company can achieve for each technology is then deduced. The identified gap in each radar represents a progress margin and potential evolution in terms of digital transformation for the company. In the following paragraph, details of each step are provided.

Step 1 - Establishing the set of technologies of industry 4.0

The first step of PPTechIP is to establish the set of I4.0 technologies judged as the most relevant based on literature review presented before. The selected ones are: *Big Data / Artificial Intelligence, RFID, Digital Twin, Cloud Computing, Augmented & Virtual Reality, Cyber Security, Internet of Things (IoT), Smart Grids, Collaborative Robots, Additive Manufacturing, Machine Learning, Simulation.* The choice of these technologies depends on strategic orientations of the company, their challenges, internal and external contexts and available resources and level of IT maturity. This set is not limitative nor locked, any update or interest from the company towards a new technology can be included and considered at this step.

Step 2 - GRAILOG : Supply Chain Decisional Model

Any Supply chain requires monitoring and follow up of its activities, processes and functions. To provide a model, useful and usable by all types of companies, a reference model called GRAILOG was build based on GRAI Method. Historically, the GRAI method (Doumeingts 1984; Ducq 2003) is the result of years of research at the IMS laboratory. The objective of this work is to extend the analysis beyond a single company towards the SC and LOGistics. The previous literature study exploring the various models, their levels, their visions, was useful to grow the reference model, defining the various functions, decision levels and decisions. GRAILOG as reference model, is built upon different complementarities and enrichment of previous models (El kihel 2021).

A manager in a SC is always confronted with the dilemma of how to match a model to its context. The idea of the GRAILOG model is to guarantee a modularity in the construction and in the use of the customized decision model to exploit a particular SC, so that the end-user can pick and choose decisions according to his expected management of the SC. Managing a SC requires visibility into key functions and processes. GRAILOG includes the macro processes inspired by SCOR model because it allows visualization by process inherent in any SC from procurement to delivery.

SCOR takes into account plan, source, make, deliver, return processes. In our opinion, SCOR vision is restrictive because it focuses on the physical flow. A SC in the Industry 4.0 era requires good forecasting by improving its customer information flow in order to gain visibility and market control. "Managing the commercial aspect" function is considered as necessary as the "industrialization" function which reinforces the "production" function and represents the upstream work in the preparation of production lines and tools in the workshops. Moreover, SC 4.0 cannot be free of the ecological aspects which evoke recycling, consumption reduction and responsible treatment. A function Managing sustainable development/social responsibility has been added and a critical function in case of major disruption (such as a pandemic) must be considered upstream. Manage Crisis function has been added in order to anticipate risk management.

Several functions are included in GRAILOG and justified by reference to the literature survey (see section 2.1) on performance measurement such as RSE, ASLOG, SCOR and standards such as ISO 9001. GRAILOG is enriched with broader functions adapted to today's SC. The steering level referring to different decision horizons, different departments and different decision granularities leads to a differentiation in levels: strategic (horizon: 3-5 years), tactical (horizon: 1-6 month) and operational (horizon: 1-2 weeks), keeping in mind that the strategic level includes decisions focusing on long terms goals, tactical level on medium term decisions focusing on means to implement and reach goals and operational decisions focusing on short terms decisions aiming to use these means.

GRAILOG enables a modularity of decisions that allows a resilient use according to the manager's needs. The choice of functions, levels, and decisions is made easier and more convenient for managers by the use of GRAILOG. The figure 3 below presents the most simplified GRAILOG decision model. The arrows represents the coordination links between decisions.<

Functions / Decision centers	Externes informati-ons	Manage the commercial	Manage industrialisation	Manage purchasing and supplies	Manage the quality of components and R.M	Manage production	Manage the quality of F.P
Strategic level H= 5 years P= 6 months	Market evolution	Commercial Strategy (CD)	Strategy of industrialisation	Purchasing and supply strategy	Quality strategy for components and raw materials	Production strategy	Quality strategy for the finished product
Tactic level H= 1 year P= 3 months	Customers Forecasted orders	Negotiate customer offers	Investment in industrial equipment and training	Define Procuremen t Policies	Define the management system and quality practices.	Realize the MPS	Respect impleme ntation time
Operationa l level H= 2 weeks P= 1 day	Customer trainings	Accepting orders	Product manufacturing method	Follow the stock	Check the conformity of the products	Start production	Manage non-conformi ties and correctiv e actions
	EI	MC	MI	MPS	MQC	MP	MQFP

Functions / Decision centers	Manage technical production resources	Managing human resources	Managing sustainable development and social responsibility	Managing crises/risks	Manage distribution	Manage returns	Internes informati-ons
Strategic level H= 5 years P= 6 months	Strategy for management technical resources	Define the company's ethical culture	Integrating the environment into the logistics strategy	Define crisis managemen t policy.	Define the downstream logistics strategy	Selection of return sites	Half-yearly activity report DG
Tactic level H= 1 year P= 3 months	Define a maintenance policy from a TPM perspective	Adapt the number of staff to the tasks and skills required	Select eco-suppliers	Establish a crisis managemen t plan.	Simulation of the transport plan.	Manage customer complain ts	Claims in progress, delay rate
Operationa l level H= 2 weeks P= 1 day	Manage preventive and corrective maintenance	Allocate and manage human resources	Eco-production	Implementa tion of an action plan	Tour planning	Product control	Daily report
	MTPR	MHR	MSDSR	MC	MD	MR	II

Figure 3. GRAILOG: A Decisional Model for the control of the SC exploitation

Step 3 - Identification of KPIs: GRAILOG KPI grid

GRAILOG is the starting point for SC control. Modular and constructible, it allows the identification of decisions in order to refine the steering variables to reach the decision objectives. The second step consists in building the performance indicators called KPI of the SC. The KPIs are always linked to the decisions and the objectives. A KPI grid has been defined based on the GRAILOG grid, and proposes a set of indicators for any proposed decision. The selected indicators are based on a thorough research of the three performance measurement frameworks (SCOR, ASLOG, BSC). The selected KPIs are referenced to the original models (see figure 4).

Functions / Decision centers	Externes informations	Manage the commercial	Manage industrialisation	Manage purchasing and supplies	Manage the quality of components and R.M	Manage production	Manage the quality of F.P
Strategic level **H**= 5 years **P**= 6 months	Market evolution	Adopt an innovative business strategy Revenues achieved/sales targets.	Strategy of industrialisation Number of production site	Purchasing and supply strategy Number of suppliers in the market.	Quality strategy for components and raw materials Quality of services from suppliers.	Production strategy Reliability rate of sales forecasts	Quality strategy for the finished product Product identification response time
Tactic level **H**= 1 year **P**= 3 months	Customers Forecasted orders	Negotiate customer offers Number of negotiations	Investment in industrial equipment and training Ability to standardize the product (number of assembly steps)	Define Procurement Policies Quantity to be manufactured	Define the management system and quality practices. The respect of the delivery deadlines. (R.M)	Realize the PDP Production capacity rate.	Respect implementation time Timeframe for implementation of the control
Operational level **H**= 2 weeks **P**= 1 day	Customer trainings	Accepting orders Forecast accuracy.	Product manufacturing method Production start-up time	Follow the stock Number of references managed in stock	Check the conformity of the products Rate of compliant products	Start production Manufacturing cycle time	Manage non-conformities and corrective actions Cost of non-compliance
	EI	MC	MI	MPS	MQC	MP	MQFP

Functions / Decision centers	Manage technical production resources	Managing human resources	Managing sustainable development and social responsibility	Managing crises/risks	Manage distribution	Manage returns	Internes informations
Strategic level **H**= 5 years **P**= 6 months	Strategy for management technical resources Equipment reliability rate.	Define the company's ethical culture Number of employees (factory, outside)	Integrating the environment into the logistics strategy Environmental cost	Define crisis management policy. Number of communication campaigns	Define the downstream logistics strategy The number of different distribution methods	Selection of return sites Number of return sites	Half-yearly activity report DG
Tactic level **H**= 1 year **P**= 3 months	Define a maintenance policy from a TPM perspective Maintenance cost	Adapt the number of staff to the tasks and skills required Number of new jobs offered each year	Select eco-suppliers The percentage of products co-designed with partners	Establish a crisis management plan. Number of people made aware of the crisis.	Simulation of the transport plan. Distances travelled in KM (vehicle geolocation)	Manage customer complaints Rate of customer complaints	Claims in progress, delay rate
Operational level **H**= 2 weeks **P**= 1 day	Manage preventive and corrective maintenance Number of machine breakdowns	Allocate and manage human resources Number of layoffs per year.	Eco-production New clean technologies	Implementation of an action plan Crisis exit plan	Tour planning Fill rate of the trucks.	Product control Rate of customer returns	Daily report
	MTPR	MHR	MSDSR	MC	MD	MR	II

Figure 4. The GRAILOG KPI Grid

The indicators developed in the GRAILOG KPI grid become controllable and measurable tools for goods, processes, services and activities related to the different decisions of the SC. These indicators must be precise and synthetic. Performance measures must be simple, significant, accessible when needed, realistic and temporally defined. They must give the most accurate and concrete view of the SC.

Step 4 - The cross study: Technologies and Indicators

The objective of this step is to relate the contribution of each technology to the reliability of the indicator. This analysis is carried out on the various functions of GRAILOG grid according to the needs expressed by the decision maker. The example used in this paper is the function "*Manage Production*". As soon as a possible correspondence between certain technologies and

KPIs is admitted, the next step will be to untangle these interrelationships in order to reveal the potential correspondences. A binary variable is associated. **1** if the technology is involved and **0** if no association is found between the technology and the KPI.

A reference level calculation is made. This index, named *LI (Level of Involvement)* reflects the ration between the number of involvement of the technologies to KPI by the total number of indicators. The baseline is calculated by level (strategic, tactical, operational). The level of involvement represents, in our vision, the standard or reference state (in %) reflecting the contribution of each technology to the smart KPIs. However, this level is not unique and absolute. It represents a vision that has the merit of representing a « reference state ». As in any system, a reference state is a starting point for a more detailed analysis later, in comparison with instantiations at a given time (t) and situations (x). In the table 2, each technology is questioned in order to know whether it contributes to the reliability of each KPI.

$$(Level\ of\ involvement = \frac{\text{Number of involvement of the technology}}{\text{The number of indicators}} \times 100)$$

			The new technologies of industry 4.0 chosen by GRAILOG model											
Function	**Decision-making level**	**Performance Indicator**	**IOT**	**Cloud computing**	**Big Data**	**RFID**	**Augmented & virtual reality**	**Collabo-rative Robot**	**Simula-tion**	**Cyber security**	**Artificial intelligence**	**3D printing**	**Digital twin**	**Smart grids**
Manage production	***Strategic level***	Reliability rate of sales forecasts		1	1				1	1	1			
		Production strategy cost (ICP)	1	1	1	1	1	1	1	1		1	1	
		Rate of commitment of technical and human resources (economic rate of return).	1	1		1	1	1	1	1		1	1	
		Reliability rate of production data	1	1	1	1	1	1	1	1	1	1	1	
	Tactical Level	Production capacity rate.	1	1			1	1	1	1	1	1	1	
		Estimated production time	1	1		1	1	1	1	1		1	1	
		Rate of compliance with the production plan.	1	1			1	1	1	1	1		1	
		Level of work in progress.	1	1	1	1	1	1	1	1		1	1	
		Number of deliveries received on time	1	1		1			1	1				
		Overall rate of return	1	1	1	1	1	1	1	1	1	1	1	
		Cost of consumption of technical resources	1	1	1	1				1				1
		Inventory turnover rate	1	1	1	1	1	1	1	1		1		
		Rate of compliant products	1	1	1	1	1	1	1	1	1	1	1	
	Operational level	Manufacturing cycle time	1	1		1	1	1	1	1	1	1	1	
		Productivity rate	1	1	1	1	1	1	1	1	1	1	1	
		Number of days of inventory of the finished product	1	1	1	1			1	1		1		
		Out of stock rate of F.P	1	1	1	1	1		1	1		1		
		Loss rate	1	1	1	1		1	1	1	1	1	1	
		Stoppage rate	1	1	1	1	1	1	1	1		1	1	
		Production / packaging cost	1	1	1	1	1	1		1	1			
		Rate of recyclable packaging	1	1	1	1			1	1			1	
	Rate of use of the technology by decision level	Number of technology use by strategic level	3	4	3	3	3	3	4	4	2	3	3	0
		Number of technology use by tactical level	9	9	5	7	7	7	8	9	4	6	6	1
		Number of technology use by operational level	8	8	7	8	5	5	7	8	4	6	5	0

		The reference level of Industry 4.0 technologies											
Function	**Decision-making levels**	**IOT**	**Cloud computing**	**Big Data**	**RFID**	**Augmented & Virtual Reality**	**Collabo-rative robot**	**Simulati on**	**Cyber security**	**Artificial intelligence**	**3D printing**	**Digital twin**	**Smart grids**
Manage production	*Strategic level*	75%	100%	75%	75%	75%	75%	100%	100%	50%	75%	75%	0%
	Tactical level	100%	100%	56%	78%	78%	78%	89%	100%	44%	67%	67%	11%
	Operational level	100%	100%	88%	100%	63%	63%	88%	100%	50%	75%	63%	0%

Table 2. Reference Study: Level of Involvement for Production Management Function

Step 5 - Comparison and analysis

For useful visualization and supporting dashboard building for managers, "radars" design has been retained. It groups together in a single diagram the 12 technologies studied with a visualization of the l*evels of involvement.* The method defines as many reference radars as there are functions and decision-making levels.

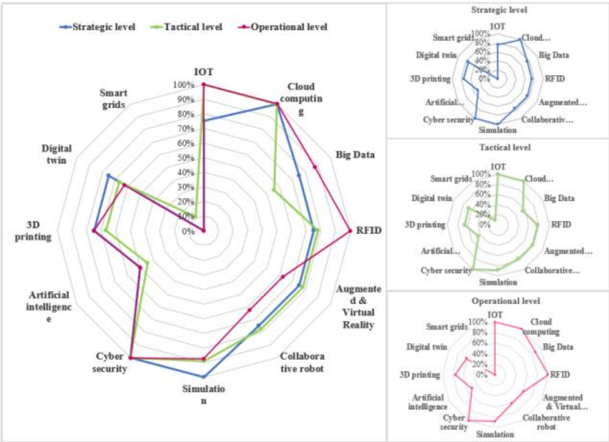

Figure 5: Reference Levels of involvement – « Manage Production »

Let's take the case of "Production Management function". Radar reveals (Figure 5) that the reference according to the three decision-making levels have roughly the same appearance of the reference levels. This implies that the technologies have a pseudo-similar impact on the KPIs of the three levels. Let’s go deeper in the analysis.

A high reference level is observed for cloud computing, cyber security and simulation (100% reference level). Stored production data can be shared, access is available to multiple users. The associated cyber security issues need to be considered and the simulation allows to study the different production strategies from the strategic to the operational level with great attention to data security. Big data analytics is integrated in almost all production activities but at different % levels. The collection of large volumes of data through the connectivity of all the sensors and actuators of the production site, even for sites that are remote, constitutes a massive database of the Big Data type. These coupled and correlated data allow predictive analysis, giving the opportunity to control, and supervise industrial equipment. It is also possible to anticipate the malfunctioning of installations and reduce the downtime of production equipment.

For Internet of Things, a strong use appears, and one can perceive the IoT as a support involved in production activities impacting the KPIs from the strategic to the operational levels. It provides improvement solutions, allows a total follow-up of products, tools, machines, equipment from upstream to downstream by supervising the supply conditions. It gives a traceability to companies to gain in performance and productivity in its operations and improve the safety of employees. RFID plays a very important role in improving the production process, especially at the operational level, allowing, through traceability systems, to reduce production costs and losses due to errors. Use of RFID tags allows to facilitate and automate the management of tooling stores.

Simulation is relevant at all levels of decision making. The simulation of production flows allows the company to manage the complexity of the production and to build scenarios in order to choose the most suitable running. That is why this technology is useful for any kind of company. Collaborative robots and augmented reality support the production function. The arrival of robotics has redefined and revalued human work, allowing the automation of repetitive tasks, which optimizes production performances. The use of Augmented Reality makes the reading of work stands more reliable and enable to accelerate the progress of tasks (assembly, quality control and maintenance) by helping operators to quickly access the standardized steps and to avoid errors.

AI is based on data from connected objects, it allows to gather data and process this information, it also allows to simulate and to evaluate multiple scenarios that allow to optimize and take decisions. In production, it can support robotization, shape and surface recognition in order to support quality control procedures or picking procedures in warehouses in order to recognize products instantly. It is interesting, but seems not essential in terms of influence on KPIs (50% in strategic and operational and 44% in tactical).

3D printing is an interesting enabler in production. 3D printing is useful for manufacturing consumable parts, avoiding procurement, and their immediate availability on the production line is interesting for limiting delays due to component shortages. 3D printing also enables the printing of spare parts that are critical for the smooth running of production and avoiding dependence on a supplier.

The use of the digital twin, to a lesser extent (but important as the simulation) is recognized in the three decision-making levels, because this technology allows to supervise the production in real time on the basis of the machine information and the real-time feedback of the smart sensors data. It is used to optimize the machines and the maintenance of production equipment and to act in real time on the system by analyzing the digital copy. It can also be used to simulate products, to simulate the constraints of tools on the production line or a complete production installation in order to make tactical and also strategic decisions.

For the Smart grids, no very significant integration is shown. A contribution to the specific indicator of energy consumption is effective because the deployment of sensors on production equipment enables to know and optimize energy consumption.

Step 6 – Analyze the margin progress through PP calculation

Once the reference level (standard radars) is established in PPTechIP, it is necessary to roll out the radars in order to establish a comparison between the reference and the considered company current level of integration and to extract the margin of progress named **PP (Potential of Progress)** which will be revealed, analyzed and proposed to the steering of the SC.
This potential for progress represents the possibility of improvement and the percentage of actions necessary to achieve the improvements (example on the radar – Figure.2, Step5): there is a PP to bring the current level of *simulation* to the reference maturity level. A progress of *+18%* is then targeted. An in-depth study is presented in the next part in order to show the application within French Car Manufacturer – PSA in Morocco.

To demonstrate the usefulness of PPTechIP in real company context, an algorithm (figure 6) is built to allow the automatisation of the approach and unfold it in any context where the inputs have been prepared. Different sets are essential to initialise {functions, decision levels, technologies, indicators…}. The algorithm will be implemented to carry out the outputs of potential of Progress per KPI for quick calculation and deeper analysis. It provides a kind of decision computer aided system to monitor the evolution of the KPI in decision manager's dashboards.

Algorithm PPTechIP

S (f): Set of functions in GRAILOG, S (k): Set of KPI GRAILOG, S (t): Set of technologies of industry 4.0
S(l): Set of levels (strategic, tactical, operational)
$S(f) = \{f_1,\ldots, f_i \mid i = 1..n\}$
$S(k) = \{k_1,\ldots, k_j \mid j = 1..m\}$
$S(t) = \{t_1,\ldots, t_q \mid q = 1..p\}$
$S(l) = \{l_1, l_2, l_3,\}$
$C_{j,q}$: assignment of technology 4.0 to KPI, $C_{j,q} \in \{0,1\}$
$I.L_c$: Involvement Level of Technology (q) to smarter KPI in (%) – Current finding
$I.L_r$: Involvement Level of Technology (q) to smarter KPI in (%) – Reference finding
PP: Potential of Progress in implementing technology (%)

$\forall i, f_i \in S(f), \forall j, k_j \in S(k), \exists\, t_q \in S(t) \mid k_j \leftarrow t_q : I.L_c = \sum_{q=1}^{r} C_{j,q} / r$

Begin
While ($i \le n$) **do**
 While ($j \le m$) **do**
  While ($q \le r$) **do**
   While ($l \le 3$) **do**
     PP_Calculation = $I.L_r - I.L_c$
   if PP > 0 **then act**
     if PP $\in$ {0, 50%} **then** improve; **else** follow up
   else
   alert
End

Figure 6: Algorithm PPTechIP used to automatize the methodology

5 Application in Automotive Industry: Case PSA

The application of *PPTechIP model* will be conducted at a major car manufacturer **Peugeot Citroen PSA (now called Stellantis)** Site Kenitra with an official headquarters in France. The group is among European leaders in the automotive industry. It also includes other companies such as GEFCO (2nd largest logistics and transport company in France). The production of a vehicle is made by the succession of hundreds of operations distributed between the assembly and the final phases. The different activities are represented in figure 7: purchase and supply, stamping, fitting, painting and assembly. Each phase is carried out independently in one building and is linked by internal logistic.

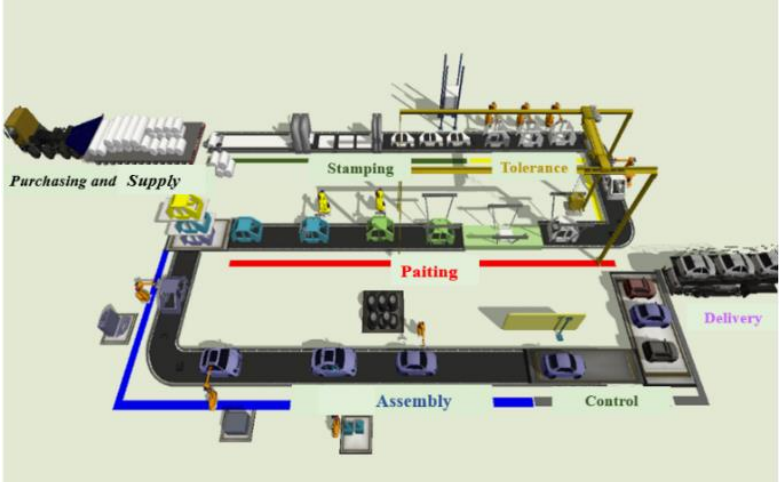

Figure 7. Production process in PSA – Site of Morocco

5.1 Data collection:

The data collected were obtained through a team entirely dedicated to the optimization of PSA supply chain. An interview phase was launched, and another formalization phase followed. The interviews and exchanges took place in close collaboration with the Production and Logistics Manager. In the frame of a larger collaboration, this work with PSA lasted 4 months with regular meetings, answers to questionnaire and model development. The scope of the SC was defined according to the priority given by PSA, the functions of the SC were retained, the decisions elaborated and the KPI built up.
The validation of the model was done with a team of engineers. Several loops were carried out (model proposal) then verification and validation before integrating the team's feedback and consolidating the result.

5.2 Implementation

The first interview with the head of production/logistics department targets the understanding of the priorities of PSA's SC. The production process and the different activities of PSA supply chain were analyzed with the managers. Regarding the elements discussed and obtained with the industrialists, it appeared relevant for PSA to have a model for the management of SC operations to reinforce the monitoring. GRAILOG was therefore appropriate as model. The industrialists showed a strong interest for this model because it takes into account the complexity of the SC as a whole, the steering activities, the decisional levels, the functions and services of the SC. Secondly, it was necessary to define the functions concerned by the study. Indeed, the advantage of the GRAILOG model lies in its modularity, i.e. the possibility to select with "plug and play" approach the prior functions that deserve a particular attention from each manager. This contextualization becomes a facilitating and resilient element allowing an appropriation and a constitution of the adapted model.
The complete model including the 12 functions of the GRAILOG grid was then presented. Indeed, GRAILOG model remains a reference model and the exhaustiveness of the functions is an ambition without being a pretention. The more SC functions are represented, the better it is, even if the flexibility and modularity of the model allows for extraction as needed. Thus, the functions considered as relevant for PSA after discussion are: *«Manage industrialization", «Manage purchasing and supply", «Manage production», «Manage technical production resources", «Manage human resources»", «Manage the crisis», «Manage sustainable*

development and societal responsibility», «Manage distribution » as represented in the PSA decision model of figure 8 below .

Functions / Decision centers	Externes informations	Manage industrialisation	Manage purchasing and supplies	Manage the quality of components and R.M	Manage production	Manage technical production resources	Managing human resources	Managing sustainable development and social responsibility	Managing crises/risks	Manage distribution	Internes informations
Strategic level **H**= 3 to 5 years for PSA **P**= 6 months	Market evolution	-Strategy of industrialisation -Multi-site production -How the products are made.	-Purchasing and supply strategy	-Quality strategy for components and raw materials -Supplier selection	-Production strategy -Realize the SOP	-Strategy for management technical resources -Invest in equipment, machinery -**Implementation of a capacity and reliability process synchronized with production needs**	Define the company's ethical culture -Personnel strategy, skills identification and recruitment plan. -**Relocation of factories (Opportunities of cheaper labor).** -**Return to investment (for all decisions related to HR)**	Integrating the environment into the logistics strategy -**Carbon footprint** -Integrate logistical constraints -Integrate societal aspects (disabled, lean-to status). -Define the environmental risk -Define a green distribution and transport policy.	Define crisis management policy. -Pre-crisis : defining the prevention plan -Analysis of the company and its environment.	-Define the downstream logistics strategy -Define annual contracts with carriers and the distribution network	Half-yearly activity report DG
Tactic level **H**= 1 year **P**= 3 months	Customers Forecasted orders	Investment in industrial equipment and training -Equipement / site allocation. -Standardize components and modularization -Identification of machines and equipement.	-Define Procurement Policies -Define the supply modes (KANBAN for example) -**JIT Policy** -MRP parts supply planning -Warehouse replenishment -Negotiate load readjustments -**Reduction of the surface, of the number of days of stock**	-Define the management system and quality practices. -Internal quality audit.	-Realize the MPS -Programing of the production and calculation of net requirements. -Manage invention levels -Plan the workload.	Define a maintenance policy from a TPM perspective -**Management and review of obscolessence** -**Means of diagnosis**	Adapt the number of staff to the tasks and skills required -**Job creation and skills development** -Planning human resource schedules -Working conditions and social protection -Development of team. -**Training of personnel according to qualified and unqualified status..**	-Select eco-suppliers -Selecting subcontractors and suppliers with the best environmental guarantees. -Managing the environment in the various stages of product manufacturing. -Compliance with environmental regulations. -The 3Rs (Reducer, Reuse, Recycle) -Identification of new advanced technologies in support of environmental compliance.	Establish a crisis management plan. Define the nature of the risk (sanitary or natural...) -Precautionary measures -Define and analyze the crisis , and its stakeholders - Addressing the risk of the SC. -**Relocate production.** -Managing internal and external communication -Create a crisis cell	-Simulation of the transport plan. -Distribution Requirements Plan (DRP). -Delivery planning -Elaboration of occasional contracts with carriers and revisions of annual contracts. -**To have partnerships with the customs (Customs and transport subcontracted)**	Claims in progress, delay rate
Operational level **H**= 2 weeks **P**= 1 day	Customer traings	-Product manufacturing method -Validate documents -Short-term intervention such as emergencies.	-Follow the stock -Order of raw materials. -Confirm order Supplier relaunch -Electronic Data Interchange (EDI)	-Check the conformity of the products -Follow-up suppliers in case of material default and establishment of clauses.	-Start production -Planning and scheduling of plants. -Lot sizing.-Improvement of the cadence -Manage packing and packaging. -Control of the workshop.	- Control of the machines and maintenance -Implementation of first level maintenance with training -Manage preventive and curative maintenance. -Manage preventive and corrective maintenance	Allocate and manage human resources. Managing the workforce. -Conflict management -Application of an internal regulation -Application of the law (labor code).	-Eco-production -Eco-packaging usage. -Recycling planning -**Supplier audits.**	-Implementation of an action plan -Build safety stocks. -Move to telecommuting. (for certain trades) -Manage employees in times of crisis. Define the continuity plan. Restitution of the data related to the crisis situation –Re-thinking the business model.	-Install the product Tour planning -Allocation of transportation to site -Management of the storage of the F.P -Transport scheduling and consolidation -Shipping procedures -Manage packaging and pack the product -Invoice -Start delivery	Daily report
	EI	MI	MPS	MQC	MP	MTPR	MHR	MSDR	MC	MD	II

Figure 8. GRAILOG / PSA supply chain

To ease grasping the usefulness of this grid, some functions can be discussed. For the function *Manage purchasing and supplies*, (1year horizon and 3 months period) the decision suggested is to define the supply modes (Kanban for example). This method of managing supplier and customer flows is opposed to traditional scheduling methods that rely on the basis of pre-determined batch sizes. After validation of this decision with the production manager, PSA works more precisely with the JIT policy between its actors (principals and subcontractors) which requires to work in good intelligence. For «*manage production*» function at the operational level (horizon= 2 weeks and period=1 day), PSA group is pursuing a reflection on the optimization of flows to increase the rate of production and reduce the changeover time period between two batches of products. For «*manage crisis*», at the tactical level (horizon=1 year and period =3 months) one of the decisions taken by PSA group, in this period of pandemic is to relocate the production by giving more project to the non-impacted factories/countries.
The purpose is to disclose important decisions and pick up inside accordingly.

5.2.1 Initial diagnosis of the 4.0 maturity

A cross study of new 4.0 technologies and KPIs was led in PSA, using PPTechIP approach suggesting overlaying the "current state" of technology with the "reference state" of maturity developed within our research team. This overlaying allows to identify the potential of progress in the development of new technologies. The analysis and scoring is done after several interviews with PSA managers. The calculation of the current level of each technology for the different functions is therefore carried out but this paper presents exclusively the function "Manage production" in order to gain clarity and not to overwhelm the reader (see Table 3).

			The new technologies of industry 4.0 chosen by GRAILOG model											
Function	**Decision-making level**	**Performance Indicator**	**IOT**	**Cloud computing**	**Big Data**	**RFID**	**Augmented & virtual reality**	**Collabo-rative Robot**	**Simula-tion**	**Cyber security**	**Artificial intelligence**	**3D printing**	**Digital twin**	**Smart grids**
Manage production	***Strategic level***	Reliability rate of sales forecasts		1	1				1	1	1			
		Production strategy cost (ICP)	1	1	1				1	1		1	1	
		Rate of commitment of technical and human resources (economic rate of return).		1					1	1		1	1	
		Reliability rate of production data	1	1	1				1	1	1	1	1	
	Tactical Level	Production capacity rate.	1	1					1	1	1	1	1	
		Estimated production time	1	1					1	1		1	1	
		Rate of compliance with the production plan.	1	1					1	1		1	1	
		Level of work in progress.	1	1					1	1				
		Number of deliveries received on time	1	1	1					1				
		Overall rate of return	1	1						1				
		Cost of consumption of technical resources	1	1						1				
		Inventory turnover rate	1	1	1			1	1	1				
		Rate of compliant products	1	1	1			1	1	1			1	
	Operational level	Manufacturing cycle time	1	1					1		1		1	
		Productivity rate	1	1				1			1		1	
		Number of days of inventory of the finished product	1	1	1				1	1				
		Out of stock rate of F.P	1	1	1				1	1				
		Loss rate	1	1	1				1	1			1	
		Stoppage rate	1	1	1				1	1			1	
		Production / packaging cost	1	1	1				1	1	1		1	
		Rate of recyclable packaging	1	1	1				1	1			1	
	Rate of use of the technology by decision level	Number of technology use by strategic level	2	4	3	0	0	0	4	4	1	3	3	0
		Number of technology use by tactical level	8	8	3	0	0	1	6	8	1	3	4	0
		Number of technology use by operational level	8	8	6	0	1	3	7	6	3	0	6	0

	The current level of Industry 4.0 technologies at PSA												
Function	**Decision-making levels**	**IOT**	**Cloud computing**	**Big Data**	**RFID**	**Augmented & Virtual Reality**	**Collabo-rative robot**	**Simulat ion**	**Cyber security**	**Artificial intelligence**	**3D printing**	**Digital twin**	**Smart grids**
Manage production	*Strategic level*	50%	100%	75%	0%	0%	0%	100%	100%	25%	75%	75%	0%
	Tactical level	100%	100%	38%	0%	0%	13%	75%	100%	13%	38%	50%	0%
	Operational level	100%	100%	75%	0%	13%	38%	88%	75%	38%	0%	75%	0%

Table 3. Actual level of Technologies 4.0 contributions at PSA – Function « Manage Production »

The results of PP are provided in figure 10. Dotted radars representing the current state of PSA are super imposed with bold radars (representing the reference state). This combined presentation allows a comparison between the two radar states in a visual way in order to disclose *Potential of Progress PP* (see figure 9). The application of each function to three decisional levels leads to 3 superimposed radars to quickly visually grasp the potential progress

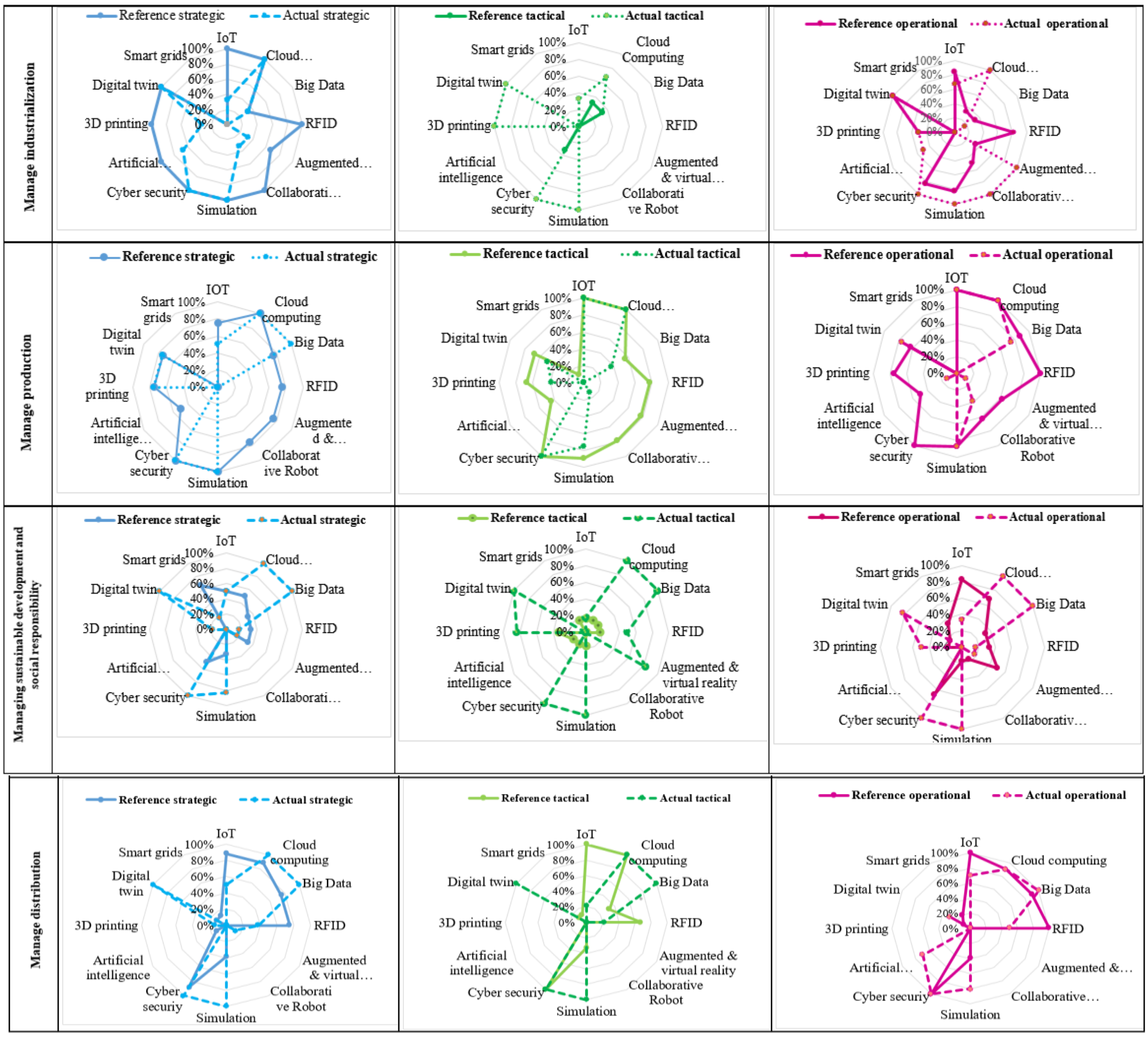

Figure 9. PP radars of the new technologies of industry 4.0 at PSA

5.3 Findings and Results

Once the observation and the comparison of the superimposed radars carried out, the potential of progress (PP) emerge for certain technologies 4.0. The Delta created by the difference between the reference level and the current level represents the margin of the potential of progress to be followed up by the company for each technology. ***PP = Reference level – Current level.*** This PP represents the possible actions and the percentage of action necessary to achieve the improvements. However, the PP can be positive and negative as well.

In order to clearly present the results of the PP calculations, a tabular representation is proposed, as a form of steering dashboard. *PP dashboard* is divided into four functions and according to the three decision-making levels. This table is therefore modular, adaptable and depends on the considered functions. The PP results are presented in Table 4. Indeed, it is proposed to highlight alert categories for decision-makers according to the positive or negative value of the PP, and according to the threshold reached, various actions are proposed among: standardize, Improve, Follow up an alert.

Standardize when PP = 0% (Current level is at reference level, no alert)

Improve when PP > 0 and PP ∈ [0%, 50%] The company is well positioned and not far from the benchmark, it can continue the improvement.

Follow up when PP > 0 and PP ∈ [50%, 100%] The company is far from the reference, corrective actions must be taken to develop the concerned technologies. It must continue the improvement.

Follow when PP < 0 and PP ∈ [-50%, 0] The company is beyond the assumed benchmark (it is better than expected), verification required but yet no alert.

Alert when PP < 0 and PP ∈ [-100%, -50%] The company largely exceeds the reference level, a risk of over quality arises, a point of vigilance must be highlighted.

As a reminder, twelve technologies were reviewed according to the three decision-making levels and for the four functions stipulated as priorities for PSA. This dashboard is an interesting and visual tool to follow the alert points to make evolving the strategy of Technologies implementation.

Functions	Decision-making levels	IoT	Cloud Computing	Big Data	RFID	Augmented & virtual reality	Collaborative robot	Simulation	Cyber security	Artificial intelligence	3D printing	Digital twin	Smart grids
Manage industrialization	*Strategic level*	67%	0%	0%	67%	34%	-33%	0%	0%	33%	67^{2}%	0%	0%
	Tactical level	0%	- 20%	0%	0%	0%	0%	-60%	-40%	0%	0%	20%	0%
	Operational level	16%	-17%	16%	83%	-17%	-17%	-17%	-17%	17%	0%	0%	0%
Manage Production	*Strategic level*	25%	0%	0%	75%	75%	75%	100%	0%	25%	0%	0%	0%
	Tactical level	0%	0%	18%	78%	78%	78%	14%	0%	31%	29%	17%	11%
	Operational level	0%	0%	13%	100%	50%	25%	0%	25%	12%	75%	-12%	0%
Managing the Responsibility and Sustainable Sustainable Development	*Strategic level*	0%	-17%	-17%	33%	50%	33%	-50%	-17%	33%	33%	17%	50%
	Tactical level	3%	-67%	-50%	-12%	-12%	17%	-50%	-67%	19%	21%	21%	33%
	Operational level	43%	-17%	-17%	30%	-20%	33%	-17%	-33%	0%	33%	7%	33%
Manage distribution	*Strategic level*	38%	-12%	0%	37%	-13%	63%	-12%	-12%	50%	-13%	12%	13%
	Tactical level	78%	0%	-22%	45%	0%	33%	-67%	0%	11%	17%	45%	11%
	Operational level	30%	0%	-10%	50%	0%	60%	-40%	0%	0%	0%	30%	20%

Table 4. PPTechIP results for technologies of industry 4.0 – PSA Kenitra

Bolded PPs mean that the company is not mature and far from the benchmark. It needs to make new efforts for some technologies like IoT, RFID, 3D printing. 3D printing technology is less developed at PSA (75% of possible progress for production and 67% for industrialization). This technology is used in few tasks such as the paint shop, the printing system allows customization in the production flow by adding very thin layer of paints. The printing process reduces the consumption of energy, water and waiting at the edge of the external delivery line. On the herringbone line, production start-up facilitates real-time exchanges between the factory and design. The evolution of models is optimized by the visualization of 3D prototypes on the line.

For the dotted PP, the company exceeds the target, is better than expected, and sometimes is beyond -50% for some technologies, and in this case it is necessary to check that there is no overinvestment on technologies. In this case, our model is able to alert PSA about over-invested technologies and will perhaps allow for a more relevant investment sweep by allocating more resources to technologies that are less endowed but that participate in the improvement of KPIs reliability. Of course, this can also be a strategic decision for the company to invest massively in a specific technology.

In the case of simulation, the application has several dark grey boxes. This technology is highly developed at PSA. This is justified because in R&D in particular, simulation allows prototyping and the choice of appropriate materials for the design of the vehicles. At the design level, it allows to analyze the interactions between the environment and the objects. This makes possible to have vehicles that consume less energy, by designing them intelligently in all stages of the design process.

One can note that cloud computing has dotted-line PPs, which means that this technology is slightly above what was established in the reference level. This technology is quite mature, sometimes a PP amount achieves -67%, this PP is in dark grey and shows a risk of over quality occurs in dark. In conclusion, the cloud is receiving a lot of attention and investment. Indeed, information exchanges and data feedbacks on PSA site are done in the cloud. The automotive industry is characterized by using Big data with partners and customers concerning their requirements. In the same way, Big data records a PP of -50%. PSA is able to capture data from connected cars, and analyzes them to offer customers personalized services. The group has a fleet of several million connected vehicles capable of collecting massive data using sensors. All data must be stored in large systems, hence justifying the usefulness of the Cloud (as confirmed by the Production Manager). Given the international competition, PSA protects all its data and strengthens the security of its network by developing cyber security because it is more exposed to cyber-attacks.
When considering augmented & virtual reality, this technology presents a potential progress that slightly exceeds the reference level, which can be explained by the interest of PSA to use this technology to develop an efficient maintenance (see table 5). This technology allows operators to be trained continuously, and their agility is reinforced by virtual reality. During this period of Covid 19, this technology is used in maintenance and remote interventions. Technicians can no longer travel to solve problems so interventions take place remotely.

For the Digital Twin at the level of the three functions, a low PP compared to the reference state is calculated, which is justified by the fact that the company does not consciously develop the DT, except at the operational level of the *Manage Production* function. By using this technology, development becomes possible throughout the life cycle of the virtual vehicle model, and allows operators to plan actions to improve performance.

For collaborative robots, it’s is noted that a PP of -33% of the function “manage industrialization” (exceeding the reference state). This technology has an impact at the strategic level by making assembly speed more reliable. For the other functions, collaborative robots are not strongly developed at PSA, but they are used in the workspace. Heavy tasks are carried out by robots and quality controls are carried out automatically and then validated by the operators.

It is concluded, thanks to the synthetic dashboard, to a strong dominance of some Industry 4.0 technologies at PSA such as, *cybersecurity, simulation, Big data, cloud computing and IoT.*
These results, from the PSA application, are consistent with the study conducted with the SCOPUS search engine presented in section 2.3.2 on the literature review. And there are some surprising but contextual absences like RFID. This technology is used in distribution and transportation activities exclusively. The RFID is not used for some processes like production because of the drying of the car body (at 70° temperature). Indeed, RFID chips are sensitive to

temperature and they may lose their expected function of remotely sending information. For some technologies, PSA does not want to spend money on installation and infrastructure which are often very expensive (connections) and prefers to invest in IoT technologies with wireless communication protocols like NbIOT, BLE, Lora, Sigfox that can ease the connectivity and data acquisition without over-investment.

5.4 Analysis and Discussion

From the diagnosis and the results obtained, the synthetic dashboard allowed to disclose technologies over-used and under -used at PSA compared to what was planned in the reference study. It allows to define the alert points to be controlled. A synthetic summary analysis of each technology at PSA and its contribution to the performance indicators is suggested in table.4. After the presentation of these results, the group worked on the improvement of some technologies having a highest priority for them and that will gradually transform the production chain of PSA.

PSA results					
Technologies of industry 4.0	**Functions**	**Décisions making level**	**PPTechIP/ results**	**Actions**	**Main insights**
Big Data	Managing the responsability and Sustainable Developpement	Tactical level	-50 %	Follow	- Able to capture data from connected cars - Analyze data to provide customers with personalized services
Artificial intelligence	Manage Industrialization	Tactical level	0%	Standarize	- Reduce energy consumption of intrusive equipment in quality control for parts and recycling.
Collaborative robotics	Manage Distribution	Operational level	60%	Follow up	- Used in the workspace - Used robotic arm for complex screwing operations - Robots act on the truck fill rate.
	Manage Industrialization	Strategic level	-33%	Follow	- To increase the reliability of the assembly speed
Augmented & virtual reality	Manage Production	Strategic level	50%	Follow	- Develop an efficient maintenance - Communicate job instructions to the operator for faster start-up. - Train operators and reinforce their versatility for virtual reality.
Cloud computing	Managing the responsability and Sustainable Developpement	Tactical level	- 67%	Alert	- All information exchanges and data feedback on PSA sites are done on the cloud computing
3D printing	Manage Production	Operational level	75%	Follow up	- Support manufacturing processes and spare parts availability - To increase the reliability of the assembly speed - Used in few tasks such as the paint shop - The evolution of the models is optimized by the visualization of 3D prototypes on the production line .
Cyber security	Managing the responsability and Sustainable Developpement	Tactical level	-67%	Alert	- Reinforces the security of industrial systems - Avoid exposure to various attacks

Table 5. Finding/ Results at PSA Kenitra

In Table 5, key insights at PSA are outlined with the amount of information shared between internal and external actors. PSA Kenitra has strengthened the Big Data technology that presents a real source of applications accompanied by Artificial Intelligence processing that allows to: avoid supply disruptions, anticipate and predict machine failures, know the needs of customers, help human resources for the recruitment and management of personnel. Following field study and recommendations, PSA group has implemented actions, has dedicated financial and human means (personal training and budget allocation) to support the improvements.

For collaborative robotics, the group integrates cobots in production and robotic arms of the type whose aim is to lighten the configuration of assembly lines. This technology relieves operators of difficult and non-ergonomic tasks. PSA Kenitra has integrated the robotic arm for complex screwing operations and thanks to the cobot, it does not disturb the operators who work around it on the different screwing operations

PSA has reinforced augmented reality in terms of quality control in certain functions such as maintenance. Today, the group wants to develop more technology in quality control to deal with problems during the manufacturing process. In a context of sophistication of industrial processes, PSA offers training to its operators in order to increase their competence. In this case, virtual reality will accelerate and facilitate the training of its operators through virtual reality tools like 3D glasses. This tool will allow to simulate the work on a manufacturing line.
Big Data, collaborative robots, augmented reality are enough mature technologies and are close to the reference maturity level . However Cloud Computing (pp=-67%) requires alert because PSA is over investing on it and could become totally dependent of this technology.

3D printing at PSA concerns elements of vehicle customization. Today, PSA is partnering with other companies specializing in 3D printing to further develop this technology. The main contribution is to increase the industrial efficiency of PSA in the manufacturing by 3D printing in order to realize complex forms in particular by the processes of injection or moulding. PSA is still investing and developing this technology (pp=75%)

6 Conclusions

Ambition to lead digital transformation and implement new technologies of industry 4.0 is claimed by many supply chains. Though, there is a lack on approaches of how to choose the relevant technologies and how to link the implementation to the monitoring improvement using KPI's. In this paper a methodology is presented starting with the modelling of supply chain decisions, deduce the prior functions and build up the KPI required for follow-up and monitoring. A reference model for SC requires: structuration, completeness, coverage, reproducibility and duplicability, and that was the target of GRAILOG decision reference model and reference grid for KPI's. Then, this paper presents PPTECH IP methodology and proposes an algorithm for computer integrated calculation to support the selection of technologies of industry4.0 in relation with KPI reliability. PSA Kenitra, automotive constructor, known for its complex Supply Chain, its international context and for its ambitions of progress and development, has been chosen to verify and validate PPTECH IP and represented a favorable and interesting field of application.

The proposed model aims to tackle as much as possible the complex reality of the SC with the various functions and indicators. Several steps have been identified: reference model formulation, development of twenty steering decisions, thirty KPIs built by function. Based on many reference models for SC but not dedicated to decisions, the GRAILOG reference model integrates, as far as possible, a maximum of functions that a SC may manage. From sales management, industrialization, production, quality, maintenance, information systems, procurement, distribution, sustainable development, social responsibility, crisis management... an effort of synthesis and ultimate exhaustiveness accompanied the intention of GRAILOG's development. This paper brings to the topic the interest of including technologies of industry 4.0 and their relationships with KPI improvements. For practitioners and managers of the SC, a methodology supporting to perceive the remaining level of improvements and the priority to give to the implementation would be welcome. Indeed, confronted to a wide range of technologies and to SC complexity, the suggested PPTechIP methodology is hopefully a step up helping to build a coherent and relevant introduction of technologies inside the SC. GRAILOG decision reference model offers the required modularity in order to be customized in any kind of industry and any sector. PPTechIP can be qualified as a first attempt to combine the analysis of technologies with their impact on KPI suggesting dashboard to monitor the potential of progress to pursue the deployment of I4.0 technologies accordingly.

The real case study conducted at PSA Kenitra leads to diverse outputs that can be reproducible to other industries: the possibility to model the just necessary domain, choosing key functions and dealing with the priorities without burdening the other functions; the possibility to design KPIs according to the needs of the manager and select the appropriate KPIs from the GRAILOG-KPI grid; the possibility of having simple, relevant and visual tools thanks to the representation of overlaid radars (dotted and bold); The possibility of having a dashboard for controlling PP (potential of progress), thanks to the alert board. The ability to identify the potential of progress (PP) to justify investments in Industry 4.0, initiate the digital shift that is required for companies.

Perspectives of this research work:

Supply chain management is a wide topic of research. In the scope of this paper, Supply chain monitoring has been prior consideration. Indeed, the Supply chain is already designed and the partners already exist with an identified product portfolio. In perspective, it would be interesting to extend GRAILOG to the emerging Supply chains. Beyond the scope of operations and monitoring existing supply chain, a GRAILOG adapted to the design of a new emerging network of partners must also be developed in future work, because the decisions are not the same and the constraints merely different. It is also possible to consider automating the GRAILOG and PPTechIP formalization in a digital tool in order to make the search for information more fluid and to allow supply chain managers to activate the right levers in their decision-making process accordingly to get at a glance the prior technologies to include and the possible progress calculation. A perspective that fits perfectly with the digital transition that supply chains are undergoing to support managers and practitioners with a valuable digital tool monitoring the progress of introduction of technologies. Another evaluation (with a likert scale for example) could improve the accurateness of the contribution. In perspective, it may be necessary to associate a scale to suggest sensitive appreciation beyond simple binary variables. The reference and standardized evaluation (crossover study and radar representation) that was done with a group of different researchers is limited to the vision of our research team skills from an academic and practitioner points of view. It represents a reference statement. It can be consolidated in the future by a questionnaire expanded to a wide panel with a more in-depth research study on 4.0 technologies, their mastery and their impacts on the international SC.

Limitations:

As for each designed model, the validity is subject to discussion regarding the undertaken hypotheses. The developed model in this paper (based on SC modelling GRAILOG and PPTechIP evaluation is built in the scope of an existing supply chain, it represents a limitation. Extending this limit is interesting and has been evoked in the perspective section (GRAILOG design is under development and soon published work is coming). Moreover, inside the methodology targeting to link industry 4.0 technologies with the SC KPIs, a binary value of (0,1) was proposed to evaluate the level of involvement which may be restrictive with a limited appreciation.

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