Using blockchain to mitigate supply chain risks in the construction industry

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Abstract: This paper proposes a model to assess blockchain technology as a tool to mitigate risks within the supply chain of small and medium enterprises in the construction industry. The methodology consists in a model based on Electre multi-criteria method where some indicators and a questionnaire useful to populate the model are identified. Since there is scant literature on the identification of risks in the supply chains of small and medium enterprises in the construction industry, as well as the definition of specific indicators to evaluate blockchain suitability as risk mitigator, this paper aims to fill the gap by including the analysis of several areas. The background introduces the topic of supply chain risk management with reference to small and medium enterprises in the construction industry. In the section devoted to the methodology, an overview of blockchain technology and its implementation in the construction sector is carried out. A list of indicators has been identified to cover the main topics needed to assess whether blockchain fits the scope of a risk mitigator for small and medium enterprises within the construction supply chain. Then, a decision-making model based on the previously identified list of indicators and a customized system of weights has been developed. It has been chosen to perform the analysis on two small and medium enterprises in the construction sector but belonging to different categorization: the first can be considered a small enterprise while the second a medium one. Every small and medium enterprise with a supply chain in the construction sector and interested in implementing blockchain can use the model to see whether improvements in performance are available due to this technology.

Keywords. Supply chain management, blockchain, construction

I. INTRODUCTION

This paper is conceived to see whether there is room to adapt blockchain technology to Small and Medium Enterprises (SMEs) that represent the backbone of the Italian construction sector. A multicriteria model has been introduced to assess blockchain suitability as a risk mitigation tool within the SME Supply Chain (SC) of the Italian construction industry.

To successfully handle an area as wide as SMEs, the topic of SC has been deep dived into, to understand what facets are mostly exposed to risks that could cause a net decrease in productivity or a slowdown in the development of a construction project. In this context, SC management plays a pivotal role mainly when conceiving companies not as single and separate entities but as a set of layers forming a SC and therefore intended to face different risks (Harouache et al. 2021).

There is scant literature on the identification of risks in the SCs of SMEs in the construction industry, as well as the definition of specific indicators to evaluate blockchain suitability as risk mitigator. Hence, this paper aims to fill the gap through an in-depth study of the SC risk management process by providing an overall picture of the main industry-related risks. Moreover, this paper is designed to provide answers to SMEs entrepreneurs who wonder whether blockchain could be the right solution for the specific context of their companies.

To compete in the global arena, SMEs should develop new innovation-based business strategies that guarantee efficiency, flexibility, and high-quality processes (Kot, 2018, Kotlar et al. 2018). Blockchain technology can be seen as a tool for reducing risk and improve performance (Casino et al. 2019, Xu et al. 2020), since its tamper-proof record makes this technology an excellent reference for tracing the origin of materials and components employed for manufacturing purposes in the Engineering to Order (ETO) sectors (Strandhagen et al. 2018).

Finally, a model based on Electre methodology (élimination et choix traduisant la réalité, French for elimination and choice expressing reality, see Del Rosso Calache et al. 2018) has been developed to provide SMEs with a decision-making tool useful to understand the opportunities of blockchain technology to act as risk mitigator, to improve SC performance.

II. BACKGROUND

In the construction industry, the continuous change over years of the international economic conditions, the globalization and the increasingly diffusion of innovative technological systems have carried to a change in the SC organization of the construction firms that have had to adapt because of the competition with more and more elevated pressure (Lu et al. 2021). The probability to do not reach the pre-defined SC performance increases because of risk to failure. To face these events, the companies should be able to adapt their SC approaches as well as developing risk management action plans (Alkhzaimi et al. 2020).

In this context, SC management plays an essential role as an organic approach to logistics planning that integrates suppliers, producers, distributors and vendors and coordinates material, information, and financial flows to satisfy demand and improve the competitiveness of the entire SC (Francisco et al. 2018, Kotlar et al. 2018, Cannas et al. 2020, Cigolini et al. 2021b). Companies can identify the SC mutual dependences and determine the main risks, their magnitude, and their likelihood. A SC risk management process should be also developed to avoid or mitigate the identified risks containing their consequences (Kot 2018).

To better understand the construction sector is important to define its value chain (Atif et al. 2019). A review of the literature shows similitudes with the definitions of construction SCs: it is the process of converting raw construction materials into processed materials to make the final product (Pozzi et al. 2019, Alkhzaimi et al. 2020, Rossi et al. 2020). Al-Werikat (2017) defined the construction sector in a different way from the manufacturing SC, describing the structure and function of the sector as a value chain that integrates all materials on the construction site, thus constructing a 'construction factory' around a final project. The construction sector is characterized by a complex value chain, which envelops on-site construction activities, together with raw materials supply and the manufacture of construction materials and products that contribute to the 'upstream' construction SC (Alkhzaimi et al. 2020).

The need to develop an efficient SC management started to arise because the construction industry is very complex and framed in a competitive environment due to the demand for top quality projects at aggressive prices (Papadopoulos et al. 2016).The SC management can have four different roles in the construction sector (see Figure 1) based on what is considered the principal element of the reasoning: the SC, the construction site, or both (Al-Werikat 2017).

In role 1 the focus is on the impacts of the SC on site activities and the goal is to reduce costs and duration of site activities. The actor that is responsible is the contractor, whose main interest is in site activities. In role 2 the focus is on the SC itself to reduce costs, those relevant to logistics, lead-time, and inventory. In role 3 the focus is transferring activities from the site to earlier stages of the SC and the goal is to reduce the total costs and duration. The actors involved in this activity are suppliers or contractors (Kotlar et al. 2018, Atif et al. 2019, Cigolini et al. 2020, Pero et al. 2020). Finally, in role 4 the focus is on the integrated management and improvement of the SC and the site production (Rossi et al. 2017, Francisco et al. 2018, Ghode et al. 2020). The main actors involved are clients, suppliers, or contractors (Papadopoulos et al. 2016).

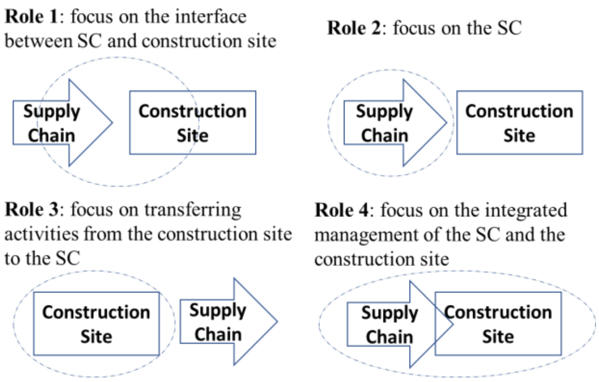

Fig. 1. 4 Roles of SC management in construction sector.

Due to the unforeseen changes, the performance of SC in the construction sector became more and more uncertain and so it has been possible to relocate the concept of risk from a probability-based concept to SC risk management (Atif et al. 2019). Risk management is based on the evaluation of two factors: firstly, the likelihood that an event may occur; and secondly, the consequences that that event may cause (Atif et al. 2019).

According to Michalski et al. (2018) risk management process is defined by three main phases: (i) risk identification, risk measurement and risk assessment; (ii) risk evaluation, risk mitigation and contingency plans; (iii) risk control and monitoring. Moreover, risks can be classified based on four types of consequences that differs in terms of frequency, severity, and predictability. One the most popular classification is given by Atif et al. (2019) who identified consequences into: (i) trivial consequences: they are characterized by very high frequency, low severity and very high predictability: (ii) small consequences: they are characterized by high frequency, low severity, and reasonable predictability; (iii) medium consequences: they are characterized by low frequency, medium severity, and reasonable predictability; (iv) large consequences: they are characterized by extremely low frequency, high severity, and minimal predictability. Table I shows the risk consequences indexes that can be applied. These indexes are useful to measure the risk ranking that aims at calculating risk exposure for each identified risk by using the following formula:

$$Risk\ exposure = risk\ consequence\ index \\ \times risk\ probability\ index$$

where the risk probability index refers to the determination of the likelihood of each risk factor.

Considering that in the construction sector each SME has its own peculiarities, it is not possible to define a unique process to assess and manage risks. The SC risk management process should be applied and customized for each situation considering the context, the environment, the dimension, and project the specific company is involved in (Papadopoulos et al. 2016).

TABLE I
RISK CONSEQUENCES INDEXES

Consequence types	Characteristics	Consequence index
Trivial	very high frequency; low severity; very high predictability	1
Small	high frequency; low severity; reasonable predictability	2
Medium	low frequency; medium severity; reasonable predictability	3
Large	extremely low frequency; high severity; minimal predictability	4

As the SC is becoming more and more complex due to many other digitization technologies, blockchain technology can integrate all elements of the SC and record data in a decentralized manner (Atif et al. 2019, Alkhzaimi et al. 2020, Cigolini et al. 2021a). This provides transparency between members and the ability to follow the record of the entire flow of information.

Implementing a blockchain in the SC can help to reduce the number of intermediaries or eliminating them, thereby reducing their costs. Thanks to its tamper-proof record, blockchain is an excellent reference for tracing the origin of the materials or components used in the manufacture of products and provides information about the supplier who manufactured them and when (Michalski et al. 2018, Xu et al. 2020). In a blockchain-based SC, digital labels are replaced by traditional barcodes that digitally store and transmit information. For example, parts and assembly components are purchased from three different suppliers worldwide and assembled on site and delivered to the customer. Thanks to the strong traceability, it is possible to identify the supplier of the parts in a relatively short time (Shemov et al. 2020). Blockchain technology can be also a tool for reducing risk. Blockchain may not be able to completely overcome current SC technologies. However, by integrating its core functions (such as data storage and retrieval methods, process automation) into the current SC process, some benefits can be realized, which can reduce risk and improve performance (Heiskanen 2017).

In the construction industry, some examples of using blockchain are maintaining digital asset records, multiple signature transactions, smart contracts, the repository of real information. In recent years, an integration has been developed between blockchain and Building Information Modelling (BIM) Technology (Khudhair et al. 2021). The use of BIM software has allowed users to simplify the development of the entire project, especially for new construction. This important structural change is characterized by the ability to use a single tool to manage the entire process in a clear and transparent way (Khudhair et al. 2021).

It is possible to highlight the three main benefits that can be achieved through the combined use of BIM and blockchain: (i) the coordination between the BIM model and a distributed database containing all the information about the processes ensures the creation of a single and reliable register, creates a collaborative environment between all participants and clearly defines the responsibilities and obligations of each of them; (ii) in order to support the creation of a collaborative environment, a distributed database allows for the storage and tracking of the intellectual property information it contains; (iii) the implementation of a smart contract related to the development of the BIM model is also relevant during the construction phase.

To summarize, the integration between the BIM model and the Blockchain illustrated so far is useful in making the activities carried out during the process explicit and visible, highlighting the honesty of those who act.

III. METHODOLOGY

Because of one of the aims of this paper is to define a list of indicators and a methodology to assess the blockchain suitability as risk mitigator for SMEs construction SCs, the criteria used to define indicators are based on the four main risks identified for the SME’s construction SCs and provides a list of fifteen indicators, three for each category that are the input of the model designed to assess the level of suitability of blockchain as risk mitigator.

The proposed model acts as a risk mitigator since it considers a list of indicators to assess whether blockchain technology is suitable to mitigate risks in construction industry. Moreover, through the model, a specific category is linked to companies allowing them to understand if blockchain technology can be a solution to mitigate risks and to increase their SC performance.

Considering that the subset of indicators refers to different issues, it has been decided that the decision aiding methodology to define a model that assesses the level of blockchain suitability is a multicriteria procedure. Within the four main reference problem types addressed by multicriteria procedures (choosing, rating, ranking and description problematic) it has been decided to define a rating procedure to assess the blockchain suitability using a multicriteria methodology, specifically one of the Electre methods.

The principal categories of indicators are: (i) objective and subjective indicators: the first type is, for example, the number of goods produced in a plant during a defined period. The subjective indicators define subjectively empirical manifestations onto symbolic manifestations, considering subjective perceptions or opinions; (ii) basic and derived indicators: the first one is from a direct observation of an empirical process and the second one is the combination of one or more indicators that can be basic or derived from others; (iii) quantitative and qualitative indicators (McCrea et al. 2006).

In the light of these categories, a list of indicators is necessary to evaluate the blockchain suitability to mitigate risks. According to Shemov et al. (2020), since the SC is defined by a network of several companies and relationships that include information, material and cash flows between all actors involved, the four main risks identified in the construction industry are: (i) inefficient communication between actors involved; (ii) delay in the project due to SC structure inefficiency; (iii) delays and lack payments; (iv) loss of material traceability.

Starting from the list of risks above, it has been possible to deduce the dimensions in which the indicators can be grouped: (i) Information and Document Flow: it consists in evaluating the sources and the channels to gathering documents and/or information as well as the quantities of documents and/or information shared; (ii) SC Structure: it encompasses the quantity and the localization of suppliers as well as the typology of contracts stipulated with them; (iii) Payments: it consists in evaluating the reliability of the different payments methods and if they are subject to delays; (iv) Materials: it consists in evaluating materials traceability and quality and if they are delivered on time with respect to the company requirements.

The list of indicators includes classification for dimensions and the name of the indicator (McCrea et al. 2006). The complete list of indicators is reported in Table II, and it contains fifteen indicators: this list is considered to contain the main topics necessary to evaluate the blockchain suitability as risk mitigator for SMEs construction SC.

For each dimension, the same number of indicators is provided to have the same level of details among dimensions that, in this way, are considered all with the same importance in the evaluating process.

Considering the list of indicators, it is possible to establish the method used for the quantitative model. In many real-world decision problems, Electre methods have been widely used for Multiple Criteria Decision Aiding.

In the operational field, the decision-aiding activity is based on three main pillars. (i) Actions that are the objects of the decision. (ii) Consequences that allow to compare an action to another one. (iii) The model of one or more preference systems that can be implicit or explicit. For each pair of actions foreseen there can be assigned one of the main situations: preference, indifference, and incomparability (Del Rosso Calache et al 2018).

Electre methods are used in situations with the following characteristics: (i) at least three criteria must be included in the model; (ii) an ordinal scale, where the data are to magnitude, or on an interval scale, where differences between data can be quantified in absolute terms, is used to judged actions. These kinds of scales cannot be used for the comparisons of differences. Therefore, it is considered artificial to define a meaningful coding in terms of preference differences of the ratios

TABLE II
LIST OF INDICATORS

Dimensions	Indicators
Company Data	Number of employees. Turnover. Level of digitalization
Payments	Reliability. Delay in receiving payments. Methods of payments
Materials	Quality. Delivery time. Traceability
SC Structure	Number and localization of suppliers. Typologies of contracts stipulated.
Information and Document flow	Channels used to gather documents/info. Archiving system and sources of documents/info

$$\frac{g_j(a_1) - g_j(a_2)}{g_j(a_3) - g_j(a_4)} \tag{1}$$

Where $g_j(a_i)$ with row i= (1, …, m) and column j= (1, …, n), is the evaluation of action a_i on criterion g_j; (iii) a strong heterogeneity concerning the nature of evaluations that exists among criteria; (iv) the decision maker may not accept a compensation for the loss on a specific criterion by gaining on another one; (v) the following has to be verified for at least one criterion: small differences of evaluations are not significant in terms of preferences, while the accumulation of several small differences may become significant (Del Rosso Calache et al. 2018).

The data needed for Electre method are: (i) $A = (a_1, a_2, \dots, a_i, \dots, a_m)$ represents the set of m potential actions; (ii) $F = (g_1, g_2, \dots, g_j, \dots, g_n)$ is a coherent family of criteria with $n \geq 3$; (iii) $g_j(a_i)$ represents the performance of action a_i on criterion g_j, for all $a_i \in A$ and $g_j \in F$; an $m \times n$ performance matrix M can be built, with $g_j(a_i)$ in row i= (1, …, m) and column j=(1, …, n). Electre Method is designed to assign a set of actions, objects, or items to ordered categories. Each category must be characterized by a lower and upper profile to which actions are compared (Del Rosso Calache et al. 2018). It uses a set of indicators defined before.

Let $C=(C_1,\dots,C_h,\dots,C_k)$ be the set of categories: the allocation of a given action a_i to a certain category C_h is the result of a comparison between the action a_i and the upper and lower profiles defining the category. Being b_h the upper limit of the category C_h and the lower limit of category $C_{(h+1)}$, a_i belongs to C_h if and only if $b_h S a_i$. It is essential to define a λ-cutting level to establish the comprehensive voting power in favor to the assertion, necessary for that action to be assigned to that category.

The importance of each category and then of each indicator with respect to the others is expressed using weights: the procedure used to define these weights is the

Analytic Hierarchy Process (AHP) by Saaty (2008) that is based on pairwise comparisons. It is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. This process is utilized to define the weight system of dimensions and indicators. In a primary analysis, the indicators’ weights were deduced considering that, within the same dimension, they have equal weight one respect to the other.

The AHP process identifies weighted indicators by defining the relative scale to measure the preference of an indicator compared to another one. AHP proposes a 1 to 9 scale where 1 means equality and 9 absolute preferences (Saaty 2008). In this study a 1 to 5 scale has been employed because it is considered easier to manage. Then, in the AHP process, a comparison matrix $n \times n$ with row $i = (1, \dots, m)$ and column $j = (1, \dots, n)$ should be derived from the pairwise comparison.

After obtaining the results of the dimension’s pairwise comparison, the priority vector and all the indexes used to evaluate the consistency of the matrix were obtained. Table III shows that the value of the consistency ratio (CR) is lower than 10% for each group of indicators and so the priority vector obtained can be considered a good approximation of the weight system as recommended by Saaty procedure. Table III also shows consistency index (CI) and random consistency index (RI) as CR comes from CI / RI ratio.

TABLE III
CONSISTENCY RATIO OF INDICATORS OF THE SC STRUCTURE DIMENSION

λ max	3.0735
n	3
CI	0.0367
RI	0.52
CR	7.07 %

Regarding the indicators’ weight system which indicator prevails in each dimension was obtained: regarding Company data, the indicator with the highest weight is “Level of digitalization” (57.14) because blockchain requires digital skills. Regarding “SC structure”, the indicator that prevails is “Number of suppliers” (61.44) because the blockchain technology is useful with complex SCs.

IV. THE MODEL

To explain the importance of each category and of each indicator in relation to the others, the weight system defined according to procedure previously described, it has been directly implemented in Electre model. To understand how the model works it is important to describe the methodology used to quantify each answer of the survey. Generally, there are four main answers quantified with a score from one to four, where one corresponds to the situation in which blockchain cannot provide an improvement in company’s performance; while four represents the case in which blockchain is useful to mitigate risks and so increase the SC performance.

Each answer has been detailed further considering a one to three value obtaining an overall scale from one to twelve that represents the scoring of the model. There are three indicators in which the scoring scale is from one to three: (i) the indicator about “Turnover”, where it has been considered the classification used to differentiate the SMEs in three categories (micro, small, medium); (ii) the indicator about “Payments’ methods”, where it has been considered only the three main methods of payments nowadays used (bank transfer, money and check); (iii) the indicator about “Channel used to gather document and information”, where it has been considered the two principal forms used to collect document and information, digital and paper form, and the mixed case. Table IV shows the number of employees used as an indicator, the question, and the relative answer with the associated score.

TABLE IV
COMPANY DATA OF THE SURVEY

Indicator	Number of employees	
Question	How many people are employed in your company?	
Answer	<10	from 1 to 3
	10 – 50	from 4 to 6
	50 – 150	from 7 to 9
	150 – 250	from 10 to 12

In the used Electre method it is important to define categories to perform a rating and consequently the definition of their profile is needed. Four different categories have been settled with their three relative profiles: (i) Category A - Blockchain completely useful: it is reached when most indicators’ scores suggest a situation that can take great advantages by the implementation of blockchain technology as a risk mitigator. In addition, the number of employees, the turnover and the level of digitalization allow the company to support the investment for this technology; (ii) Category B - Blockchain useful: there are a lot of elements that can be improved thanks to blockchain technology, but it is not guaranteed that the overall process can take advantage from this implementation; (iii) Category C - Blockchain suggested but not useful: it includes companies for which blockchain can provide some occasional improvements and so it is suggested but considered not useful to mitigate risks and so increasing the SC performance; (iv) Category D - Blockchain completely useless: in this category are included the companies that do not take advantages by the implementation of this technology.

Table V shows the profiles that are defined with rational numbers and not integers because it is less complicated assign each answer to the different categories: the attribution is immediate and so other logics are not required. The values are given and represent the advantages (expressed by figures) that companies can get due to the implementation of blockchain technology: for example, profile A can take greater advantages from the implementation of blockchain than profile B.

TABLE V
PROFILES

Profile	Value
Profile D – C	3.5
Profile C – B	6.5
Profile B – A	9.5

The model will display a final category and a category for each specific dimension: it has been considered essential to have the categorization of dimensions because this allows a more detailed elaboration of the result.

V. RESULTS

Two model applications are provided to evaluate the logics and the process implemented. It has been chosen to perform the analysis on two SMEs in the construction sector but belonging to different categorization: the first can be considered a small enterprise while the second a medium one. It is important to specify that the two companies are both located in the same area and so their SCs are facing similar problematics.

(I) Small enterprise: Company A

Considering the answers provided during the interview, Company A can be classified as a small enterprise: the number of employees is higher than 10 and the turnover is slightly higher than 2 million. Moreover, the level of digitalization is not so low but there are not initiatives in places that allow the company to be considered in a process of digital transformation. As regards the SC structure, the number of suppliers is higher than 50 and almost all the contracts are based on long term relations. The suppliers are all located within 100 km with respect to the company. Finally, the archiving system of documents and information sources is well organized. The category “SC Structure” hits category A and, according to the categories previously discussed, blockchain technology appears highly recommended and useful. However, the final category obtained is C: “blockchain suggested but not useful”. For example, in this case, the dimension “company data” has the λ-cutting level equal to 3.99 and the weight of the dimension equal to 6.65. In fact, the final category assigned is the one for which the sum of the weights of the criteria in favour is greater than or equal to the threshold λ.

(II) Medium enterprise: Company B

Considering the answers provided during the interview, La Spiga can be classified as a medium enterprise: the number of employees is higher than 50 and the turnover is greater than 10 million. Furthermore, the level of digitalization is low, but some initiatives are in place to increase and improve the situation. As regards the SC structure, the number of suppliers is around 50 and most contracts are based on long term relations. The localization of suppliers is strongly related to materials, but in general they are all located in 250 km. The results of the scores attributed by the interview to each indicator and the final category and each dimension’s category were obtained. The final category registered is Category B “Blockchain useful”. The overall result is influenced by the fact that the dimensions with the highest weight scores B: the company can take advantages from the implementation of blockchain technology in more than one area of the SC.

VI. CONCLUSIONS

This paper has focused on the implementation of blockchain technology as risk mitigator for SMEs’ SCs in the construction industry. A specific methodology to evaluate the blockchain suitability has been developed so that each company categorized as a SMEs can assess its situation and finally take the decision to implement or not this technology. The aim of this paper is also to define which are the problems of construction SC and consequently which are the risks that SMEs must face at SC level.

The paper’s principal outcome is the definition of a model based on Electre multicriteria analysis method, to assess the blockchain suitability as risk mitigator for SMEs’ SC in construction industry. Considering that this methodology consists of a rating procedure, four categories in which each company can be inserted has been defined. To provide results, the model is based on two inputs: the first are the answers provided to the survey based on a list of indicators and the second is a system of weights. The system of weights represents the importance of each dimension, and then each indicator within the same dimension, and is obtained following AHP process (Saaty 2008).

Since literature concerning the concept of indicators to evaluate blockchain suitability does not exist, a process to identify them is required. Starting from the risks identified, it has been possible to deduce the dimensions in which the indicators can be grouped: each risk highlights a specific area in which the implementation of blockchain could benefit and so needs to be considered to evaluate if this technology is useful for that company. The four dimensions are: Information and Document Flow, SC structure, Payments, and Materials. In addition to these four dimensions, some data about the company are considered: number of employees, turnover, and the level of digitalization. Generally, there are four main answers quantified with a score from one to four, where one corresponds to the situation in which the blockchain cannot provide an improvement in company's performance; while four represents the case in which the blockchain is useful to mitigate risks and then can increase the SC performance. The importance of each dimension and of each indicator with respect to the others is expressed using weights. Two SMEs are considered (Company A and Company B) to evaluate the process implemented and the model showed a final category.

Regarding Company A, considering the answers provided during the interview and according to the model, the final category is C: "Blockchain suggested but not useful". Regarding the second company the final category registered is Category B: "Blockchain useful".

In conclusion, it is possible to state that this model can be considered an effective tool that allow companies to evaluate if blockchain technology could act as risk mitigator and so improve its SC performance. As regards the future developments of the model, it could be relevant to refine the list of indicators considering a wider context.

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