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A Quantitative Blockchain-Based Model for Construction Supply Chain Risk Management

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Abstract: Although the use of Blockchain Technology in construction industry has been limited, nowadays several cases of adoption of this technology in construction sector can been identified. Such examples consist of maintaining digital asset records, timestamps for contracts or transactions, multiple signature transactions, smart contracts, and the repository of real information. This paper proposes a methodology consisting of a Electre Tri multi-criteria analysis method where a list of indicators and a questionnaire are used to fill a model that can be applied to evaluate the suitability of blockchain technology as a tool to mitigate supply chain risks that small and medium enterprises face in the construction industry. The model has been applied to two companies operating in the construction industry. This study contributes to the existing literature by quantitatively assessing the adoption of blockchain technology on two real case studies – company Alpha and company Beta – to limit supply chain risk in the construction sector. The dimensions considered in the analysis are company data, payments, materials, supply chain structure and information and document flow. According to the findings, the model suggests that for company Alpha blockchain technology is recommended but not useful to mitigate risks and so improving supply chain performance. On the contrary, results show that for company Beta the implementation of blockchain technology is useful.

Keywords: Supply chain management, Blockchain technology, Construction industry

Introduction

Nowadays, in the construction industry, risks cause a net decrease in productivity and a slowdown in the project process (Al-Werikat, 2017). The analysis of the Italian construction sector has reserved important attention because it is considered of strategic importance (Kim et al., 2020; Cigolini et al., 2022), since deals with the structures and infrastructures, which can be used by all other sectors (Cannas et al., 2020; Rossi et al., 2020) involved in the European economy and society (Harouache et al., 2021).

Small and medium enterprises in Europe and Italy are characterized by low Supply Chain (SC) performance level (Mafundu & Mafini 2019; Cigolini et al., 2022). The recent Covid-19 pandemic has caused a chain reaction in all economic sectors around the world, exacerbating this situation. Although signs of recovery are weak, Italian small and medium-sized companies seem not to have recovered from the 2008 financial crisis and have long been plagued by low productivity (Ferreira de Araújo Lima et al., 2021).

In this context, Supply Chain Management plays pivotal role especially because today, due to increasing globalization, SCs are more fragile than they used to be (Layaq et al., 2019; Pero et al., 2016; Amico et al., 2022; Franceschetto et al., 2022). Because of cheap labour abroad, many companies manufacture or source products internationally. This creates many types of risks in the SC appropriately managed with the risk management process (Shemov et al., 2020) where risks are dealt with suitable risk reduction techniques.

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Blockchain technology can be indeed a tool for reducing risks due to its tamper-proof record (Xu et al., 2020; Difrancesco et al., 2022; Amico & Cigolini 2023). Blockchain technology is used to trace the origin of the materials or components used in the manufacture of products (Xu et al., 2020). Small and medium enterprises, to compete with the other global players, should develop new innovation-based business strategies that ensure efficiency, flexibility, and high-quality processes (Pozzi et al., 2019; Franceschetto et al., 2023). Digitizing processes means moving away from paper and toward online and real-time information sharing to ensure transparency and collaboration between the actors involved in the process. One reason for the industry's low productivity is that it still relies primarily on paper to manage its processes (Difrancesco et al., 2022; Amico & Cigolini 2023), and deliverables, such as blueprints, project drawings, purchase orders and supply chains, equipment records, and daily progress reports (Kim et al., 2020).

Literature related on the classification of risks in the SCs of small and medium enterprises in the construction industry, as well as the definition of specific indicators to evaluate blockchain suitability as risk mitigator, is scant. Thus, this paper aims to fill this gap by understanding, through a model based on *Electre Tri* methodology (élimination et choix traduisant la réalité, French for elimination and choice expressing reality, see Del Rosso Calache et al., 2018) whether small and medium enterprises can adopt blockchain technology as a risk mitigator tool to improve companies SC performance. Moreover, this study allows small and medium enterprises to understand if blockchain could be the right solution for the specific context of their organization. In fact, this paper can help to catalogue and study various aspects and the related risks of the SC by providing a clear outcome in terms of adaptability of blockchain technology to a fragmented and heterogeneous context such as that of small and medium enterprises in the construction industry.

The paper is structured as follows: section 2 is devoted to the description of the research background to define the SC of the construction industry and the related risks as well as the main characteristics of blockchain technology. Section 3 describes the methodology adopted while section 4 illustrates the model. Section 5 shows the main findings. Finally, section 6 draws some conclusions and suggests future research paths.

Background

Construction SCs are complex systems especially when a variety of site materials and parties (like suppliers and sub-contractors) are involved in a construction project (Papadopoulos et al., 2016). The more people are engaged (e.g., first tier, second tier suppliers and other tiers of sub-contractors, see Rossi et al., 2017, Pero et al., 2020, Afraz et al., 2021), the more complex is the project. Furthermore, construction industry deals with complex SCs because more worker, parties and materials are required to a specific project. A construction project necessitates collaboration and cooperation among SC actors to define the best planning and organization for the project (Gosling et al., 2016).

According to Koskela et al. (2020), the construction SC can be differentiated as a converging SC since all materials are directed to the construction site where the object is assembled from incoming materials. Moreover, construction SC is fragmented since construction contractors, suppliers and other participants are active in different stages of the project, and the distribution of responsibility and authority could change over time. Finally, construction SC is temporary because when a construction project is completed, all participants and companies involved are usually dismissed as soon as all the actors participating in the project complete their duties.

Furthermore, the construction SC is composed by the following three elements. (i) The primary SC that is the stream that delivers the materials used in the final stage of the construction process. (ii) The support chain is in charge for providing expertise and equipment that facilitate the realization of construction project (e.g., scaffolding and excavation supports). (iii) The human resource SC that includes the supervisory staff and labour useful for the construction process. Hence, the construction SC consists of the human resource SC, the support chain, the primary chain, and it is also characterised to be temporary, make to order, complex and converging (Al-Werikat, 2017). According to Papadopoulos et al. (2016) most of the issues in the construction industry arises at the interfaces between the various activities or roles and are due to the complex nature of the construction environment. The main issues concern the so-called design interface phase between the client and field contractor that embraces several difficulties in defining and then realizing client's wishes.

Moreover, within the engineering phase between the field design contractor and the engineering contractor – the so-called engineering interface – some documents may prove to be incorrect the design can change and –

consequently – the approval of the design changes can be very long. Within the procurement phase between the engineering contractor and the procurement actors there is the so-called vendors interface, and some drawings may show inaccurate data, or they are not usable by vendors. Within the construction phase, some issues can occur between vendors and suppliers: for example lack of coordination, collaboration and commitment between suppliers, poor quality of materials and components. In the completion of the project between the site and the commission contractor – the so-called commissioning interfaces – some issues could be related to safety issues and difficulties with local communities. Finally, after commissioning there is the so-called operation interface: there can be problems due to unresolved quality and technical issues, delayed operational time due to late completion (Nanayakkara et al., 2021).

All the previous mentioned issues are related to the concept of risk. SC risk is an adverse event since it negatively influences the desired performance of an industry (Layaq et al., 2019). In the construction industry, examples of risks are related to demand (e.g., order fulfilment errors, inaccurate forecasts due to longer lead times, product variety) and inventory (e.g., costs of holding inventories, rate of product obsolescence and supplier fulfilment, see Pero et al., 2020; Ferreira de Araújo Lima et al., 2021).

The risk management process is a useful method to limit these SC risks and it is defined by five phases: risk identification, risk measurement, risk assessment, risk evaluation and risk control and monitoring. Such process allows to mitigate all the challenges that small and medium enterprises must face. To compete with the other global players, small and medium enterprises should develop new innovation-based business strategies that ensure efficiency, flexibility, and high-quality processes (Pournader et al., 2020).

Digitizing processes means moving away from paper and toward online and real-time information sharing to ensure transparency and collaboration, timely progress and risk assessment, quality control, and ultimately, better and more reliable results (Difrancesco et al., 2022; Amico et al., 2022). Blockchain technology offers to small and medium enterprises the opportunity to increase productivity. Blockchain technology can record data, transferred though all the actor involved in the SC, in a decentralized manner. This provides transparency between members and the ability to follow the record of the entire flow of information. This information is verifiable and allows the origin to be traced and completed (Pournader et al., 2020).

One of the main benefits of adopting a blockchain technology is that it is highly effective and transparent to all parties involved. Blockchain is typically adopted for capital construction projects and complex contracts. Throughout the project lifecycle, blockchain technology ensure that all parties under contract are collaborating at all levels. Blockchain technology can ensure that all operations are always performed in accordance with the agreed-upon terms and conditions (Pournader et al., 2020; Amico et al., 2023). Finally, blockchain technology eliminates mutual dependence on the central authority. Its decentralization increases the importance of network effects (Kim et al., 2020).

Methodology

This section introduces the methodology used to outline the indicators to evaluate blockchain suitability for the small and medium enterprises construction SCs. Fifteen indicators (three for each category) are the input of the model designed to assess the level of suitability of blockchain as risk mitigator. Considering that the subset of indicators refers to different issues, the decision aiding methodology to define a model that assesses the level of blockchain suitability is a multicriteria procedure known as Electre (Norese & Carbone, 2014).

According to the research background discussed in the previous section, the main risks identified in the construction industry are the following ones. (i) Inefficient communication between the actors involved. (ii) Delay in the project due to SC structure inefficiency. (iii) Delays and lack payments. (iv) Loss of material traceability. Starting from these risks the dimensions in which the indicators can be grouped are defined. Company Data refer to the number of employees, company's turnover, and level of digitization. Payments are described by their reliability, the delay in receiving payments and the methods of payments. Materials are assessed in terms of quality, delivery time and traceability. SC Structure is defined by the number and localization of suppliers and the types of contracts. Finally, the information and document flow is referred to the channels employed to gather documents, archiving system and sources of documents.

These dimensions have the purpose to take into consideration all the worthy elements to evaluate blockchain suitability to mitigate risks. The importance of each dimension and then of each indicator with respect to the others is expressed using a procedure to define weights. The procedure is the Analytic Hierarchy Process (AHP, see Saaty, 2008) and it is based on pairwise comparisons. The first step of AHP procedure is to define a scale of preference from 1 to 5 where 1 means equality and 5 means maximum preference. 1 = Equality, 2 = Minimum preference, 3 = Medium preference, 4 = Great preference, 5 =Maximum preference.

The second step is to perform the comparison matrix (m × n) with row i= (1, …, m) and column j = (1, ..., n). Such comparison matrix is defined from the pairwise comparison. The comparison matrix has always 1 on the diagonal and it is positive, reciprocal, and consistent. Positive means that $a_{ij}>0$. Reciprocal means that $a_{ij}=1/a_{ji}$. Consistent means that $a_{ij}=a_{ik}/a_{jk}$.

Once the comparison matrix is calculated, the third step consist of defining the priority vector that can be described as the normalized eigenvector of the matrix. The procedure chosen to define the priority vector is the so-called eigenvector method where power iterations (Saaty, 2008) are required in order that the algorithm produces a nonzero vector considered a good approximation of the eigenvector corresponding to the greatest eigenvalue of the matrix λ max, called principal eigenvalue. In this way, in the comparison matrix the inconsistency will be distributed among all the elements of the matrix and the columns will be gradually close to proportionality.

When the consistency ratio is close to zero, the priority vector can be declared as the best expression of the weight system that will be used in the Electre Tri method. To evaluate the consistency ratio, the consistency level of the comparison matrix through the computation of the principal eigenvalue must be evaluated. The principal eigenvalue is obtained from the sum of the products between each element of the priority vector and the sum of the columns of the comparison matrix.

According to Saaty (2008), in a consistent reciprocal matrix, the largest eigenvalue is equal to the size of the comparison matrix. Meanwhile, if some inconsistencies are taken into consideration, it is required a measure of consistency using consistency index (CI), where CI = $(\lambda_{max} - n)/(n-1)$ that measures the level of consistency as a deviation from the size of the comparison matrix. The consistency index needs to be compared with the random index that is defined as the result of the average value obtained from 50,000 computation of the consistency ratio of a matrix with the entries above the main diagonal at random from the 17 values {1/9, 1/8, …,1, 2, …,8, 9} and the entries below the diagonal by taking reciprocals (Saaty, 2008). In Table 3 the values obtained from one set of simulations for matrices of size 1, 2, …,15 is illustrated. The result of this comparison is the consistency ratio (CR), where CR = CI/RI.

The analysis deals with a 5x5 matrix regarding dimensions while 3x3 concerning indicators, so the Random Index (RI) is 1.11 and 0.52, respectively (see Table 1).

Table 1. Random Index.

	Random Index Values				
Matrix Order	1	2	3	4	5
RI	0.00	0.00	0.52	0.89	1.11
Matrix Order	6	7	8	9	10
RI	1.25	1.35	1.40	1.45	1.49
Matrix Order	11	12	13	14	15
RI	1.52	1.54	1.56	1.58	1.59

When the consistency ratio is lower or equal to 10 percent the inconsistency can be considered acceptable and consequently the priority vector a good approximation of the weight system (Saaty, 2008). This process is employed 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. Then, it has been realized that there are some indicators with more importance that the others belonging to the same dimensions and so the AHP process has been performed to define indicators weights.

Model

This section outlines the model and provide the main results obtained from the priority vector of the considered dimensions (company data, payments, materials, SC structure, information, and document flow, see Table 2) as well as the indexes used to evaluate the consistency of the matrix (see Table 3).

Table 2. Priority vector.

Dimensions	Priority Vector	Category Weights
Company Data	0.0665	6.65
Payments	0.1820	18.20
Materials	0.1718	17.18
SC Structure	0.3296	32.96
Information and Document flow	0.2501	25.01

Table 3. Consistency indexes.

Categories	Values
λ_{max}	5.4
N	5
CI	0.1016
RI	1.11
CR	9.15%

The value of the consistency ratio (CR) is lower than 10% and so the priority vector can be considered a good approximation of the weight system (Saaty, 2008). Regarding the dimension's weight system, it can be observed that "SC structure" is considered the main dimension according to the pairwise comparison executed, so the scores obtain within this dimension are relevant in determining the final category. Meanwhile, "Company data" is considered less important when compared to others. The other three dimensions (Payments, Materials, and Information and Document flow) are almost at the same level of importance in fact none of them is so relevant in the final category definition when compared to the others.

Considering "SC structure" dimension, Table 4 shows the results obtained from the indicators' priority vector.
The indexes used to evaluate the consistency of the matrix are: λ_{max} that is equal to 3.0735, the number of indicators equal to 3, the consistency index equal to 0.03668, the random index equal to 0.52 and the consistency ratio equal to 7.07%. Also in this case, the value of the consistency ratio 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 (Saaty, 2008).

Table 4. Priority vector of indicators of the SC Structure dimension.

	Priority Vector	Category Weights
Number of suppliers	0.6144	61.44
Suppliers' localization	0.1172	11.72
Typologies of contracts stipulated	0.2684	26.84

Regarding the indicators' weight system, it can be observed that in "SC structure" dimension the prevailing indicator is "Number of suppliers" because blockchain technology is useful with complex SCs. To explain the importance of each category and of each indicator, in relation to the others, the weight system defined according to procedure described has been directly implemented in the Electre Tri model.

Then, to fill the model, a questionnaire is formulated considering the three indicators related to "SC structure" dimension (number of suppliers, suppliers' localization, and typologies of contracts stipulated). For each indicator a specific question is formulated. Then, all the possible answers (four for each indicator) are quantified with a score from one to four where one corresponds to the situation in which blockchain technology 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. Consequently, each answer considers a one to three value obtaining an overall scale from one to twelve that represents the scoring of the model. For each question, answer (i) gives a score from 1 to 3; answer (ii) from 4 to 6; answer (iii) from 7 to 9 while answer (iv) from 10 to 12.

According to the first indicator – the number of suppliers – the following question is formulated.

How many suppliers are involved in your company's SC?

The possible answers are: (i) less than 10 suppliers. (ii) Between 10 and 30 suppliers. (iii) Between 30 and 50 suppliers. (iv) more than 50 suppliers.
For the second indicator – suppliers' localization – the question formulated is as follows.

Where are located your company suppliers in relation to your company?

The possible answers are: (i) less than 20 km; (ii) Between 20 and 100 km; (iii) Between 100 and 200 km; (iv) more than 200 km.
Finally, for the third indicator – typologies of contracts stipulated – the related question is the following one.

How often your company use long term contract with your suppliers?

The possible answers are: (i) never; (ii) a small percentage; (iii) the vast majority; (iv) always.
After formulating the questionnaire, in the Electre Tri method, to perform a rating, specific categories must be defined and, consequently, the definition of their profile is needed (Saaty 2008). Four different categories have been settled with their three relative profiles (see Table 5).

Table 5. Profile values.

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

Category A means that blockchain technology is completely useful for small and medium enterprises and is reached when most indicators' scores suggest a situation that can take great advantages by the implementation of blockchain technology as a risk mitigator. Category B means that blockchain is useful and it indicates that there are several features that can be improved thanks blockchain technology, but it is not guaranteed that the overall process can take advantage from this implementation. In Category C the implementation of blockchain is suggested for small and medium enterprises but is not useful. In fact, this category includes firms for which blockchain can provide some occasional improvements and so it is suggested but considered not suitable to mitigate risks and so improving the SC performance. Finally, Category D means that blockchain is completely useless, thus firms do not benefit by the implementation of this technology.

Results

In this section, two model applications are provided to evaluate the process implemented in two real companies operating in the construction sector and differently categorized. The former (Alpha) can be considered a small enterprise while the latter one (Beta) is medium-sized company. The two companies are both located in the same area and so their SCs are facing similar issues.

Company Alpha can be classified as a small enterprise since the number of employees is higher than 10 and the turnover is slightly higher than 2 million. Moreover, the level of digitalisation of the company does not put in place significative initiatives thus, Alpha cannot be considered a digitized firm. Payments are received often on time while the materials flow in some cases is not completely transparent. The SC structure is characterized by several suppliers higher than fifty and almost all the contracts are based on long term relations. The suppliers are all located within 100 km with respect to the firm. Finally, the documents and information sources are received both in paper and in digital form, thus the archiving system is quite well organized.

Table 6 shows the model results for company Alpha. According to the model proposed in this study, the final category obtained is C: "Blockchain suggested but not useful". The overall result is highly influenced by the "Company data", "Payments" and "Information and Documents flow" dimensions.

Company Beta is a medium enterprise since the number of employees is greater than 50 and the turnover is more than 10 million. Until now, the level of digitization is quite low. The payments are usually reliable but when the company operates as a subcontractor there some cases in which the payment is not guaranteed. However, the payments are almost never received on time.

Table 6. Company Alpha model results.

Dimensions	Indicators	Weights		λ-cutting level	Category profile
		Dimensions	Indicator		
Company data	Number of employees	6.65	0.95	3.99	C
	Turnover		1.9		
	Level of digitalization		3.8		
Payment	Reliability	18.2	2.97	10.92	C
	Delay in receiving payments		9.82		
	Methods of payments		5.4		
Mate-rials	Quality	32.95	2.01	10.3	A
	Delivery time		4.60		
	Traceability		10.55		
SC structure	Number of suppliers	17.17	20.24	19.77	A
	Suppliers' localization		3.86		
	Typologies of contracts stipulated		8.84		
Information and document flow	Channels used to gather documents	25.01	3.49	15.01	C
	Archiving system		13.20		
	Sources of documents		8.31		

Regarding materials, they are received often according to project requirements and ISO standard. Meanwhile, sometimes materials arrive later with respect to the project timing. Regarding the SC structure, the number of suppliers is around 50 and most contracts are established on long term dealings. Usually, suppliers are located 250 km from company Beta.Finally, regarding information and documents flow, the archiving system need improvement since the number of documents are huge. Table 7 shows the model results for company Beta and 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 results obtained leave room to several insights. If companies obtain as a result for which the blockchain technology is not recommended or useless, there is the possibility to perform a deep dive analysis by understanding what the areas are where the implementation of this technology is not suggested. In fact, results show if there is a particular area where the implementation can provide an increase in SC performance

In the case of company Alpha, despite its final category is C, "materials" and "SC structure" dimensions reached category A showing that for these two dimensions blockchain technology is completely useful. It means that blockchain technology could improve materials traceability, quality, and the delivery time with respect to the company requirements. Moreover, blockchain technology can be useful since it can improve the optimum number and localisation of suppliers as well as the typology of contracts stipulated with them. The other three dimensions (company data, payment and information and document flow) have reached as final category C showing that blockchain technology is suggested but not useful for the company.

In the case of company Beta, "company data" and "information and document flow" dimensions reached category C. Also in this case, blockchain technology can be suggested but not useful for the company, especially in evaluating the sources and the channels to gathering documents and information as well as the quantities of documents and information shared. On the contrary, "payment", "materials" and "SC structure" dimensions show that blockchain is useful specifically by evaluating the reliability of the different payments methods and if payments are subject to delays. Finally, blockchain technology can be useful in improving SC indicators as well as quality, traceability, and delivery time of materials.

Table 7. Company beta model results

Dimensions	Indicators	Weights		λ-cutting level	Category profile
		Dimensions	Indicator		
Company data	Number of employees	6.65	0.95	3.99	C
	Turnover		1.9		
	Level of digitalization		3.8		
Payment	Reliability	18.2	2.97	10.92	B
	Delay in receiving payments		9.82		
	Methods of payments		5.41		
Materials	Quality	32.95	2.01	10.3	B
	Delivery time		4.61		
	Traceability		10.55		
SC structure	Number of suppliers	17.17	20.24	19.77	B
	Suppliers' localization		3.86		
	Typologies of contracts stipulated		8.84		
Information and document flow	Channels used to gather documents	25.01	3.49	15.01	C
	Archiving system		13.2		
	Sources of documents		8.31		

Conclusions and Future Research Paths

This paper focused on the definition of the main issues related to construction supply chain by investigating the main risks that small and medium enterprises have to face at supply chain level. Moreover, this paper explored the implementation of blockchain technology as risk mitigator for small and medium enterprises' supply chains in the construction industry.

The methodology adopted consists of a literature review and a quantitative model based on Electre Tri multicriteria analysis method. The main outcomes of the literature review showed that construction supply chain faces several issues generated at the interfaces between the various activities, for example design, engineering vendor's interfaces, as well as commissioning and operation interfaces.

The model performed in this paper aimed to assess the blockchain suitability as risk mitigator. This model was applied to two real companies, namely Alpha and Beta. Company Alpha is a small firm while company Beta a medium one. The model is based on a questionnaire – and then the related answers – built on a list of indicators (number of employees, turnover, level of digitalization, payments' reliability, delay in receiving payments, payments methods, quality, delivery time and traceability of materials, number and localization of suppliers, typologies of contracts stipulated with suppliers, channels used to gather documents and information, archiving system document and sources). Moreover, the model is built on a system of weights that represents the importance of each dimension (company data, payments, materials, supply chain structure, information and document flow). Then, a rating procedure was assessed where four categories has been defined: category A means that blockchain technology is completely useful; category B that blockchain is useful; category C that the technology is recommended but not useful and finally category D where blockchain technology is considered completely useless.

Findings show that for company Alpha blockchain technology is suggested but not useful because company data, payment and information and documentation flow dimensions obtained weights associated with profile category "C". Regarding company Beta, the final category obtained is "B", thus blockchain technology is considered useful for the company.

The model adopted in this study is an effective tool that allows small and medium enterprises to evaluate if the blockchain technology could act as risk mitigator and so improve firms' supply chain performance. As future research paths, other studies could enhance the number of indicators considered in the model. Moreover, other research could consider different industries in which blockchain technology can be implemented, for example the apparel or transport sectors.

References

Afraz, M. F., Bhatti, S. H., Ferraris, A., & Couturier, J. (2021). The impact of supply chain innovation on competitive advantage in the construction industry: Evidence from a moderated multi-mediation model. *Technological Forecasting and Social Change, 162,* 120370.

Al-Werikat, G. (2017). Supply chain management in construction. *International Journal of Scientific and Technology Research*, *6*(3), 106-110.

Amico C., Cigolini R., & Franceschetto S. (2022a). Supply chain resilience in the European football industry: the impact of Covid-19. *Proceedings of the Summer School Francesco Turco*.

Amico, C., Cigolini, R., & Franceschetto S. (2022b). Using blockchain to mitigate supply chain risks in the construction industry. *Proceedings of the Summer School Francesco Turco*.

Amico, C., & Cigolini, R. (2023). Improving port supply chain through blockchain-based bills of lading: a quantitative approach and a case study. *Maritime Economics and Logistics*, https://doi.org/10.1057/s41278-023-00256-y

Cannas, V., Ciccullo, F., Cigolini, R., & Pero, M. (2020). Sustainable innovation in the dairy supply chain: enabling factors for intermodal transportation. *International Journal of Production Research*, *58*(24), 7314-7333.

Cigolini, R., Gosling, J., Iyer, A., & Senicheva, O. (2022a). Supply chain management in construction and engineer-to-order industries. *Production Planning and Control*, *33*(9-10), 803-810.

Cigolini, R., Franceschetto, S., & Sianesi A. (2022b). Shop floor control in the VLSI circuit manufacturing: a simulation approach and a case study. *International Journal of Production Research*, *60*(18), 5450–5467.

Del Rosso Calache, L. D., Galo, N. R., & Ribeiro Carpinetti, L. C. (2018). A group decision approach for supplier categorization based on hesitant fuzzy and Electre Tri. *International Journal of Production Economics*, *202*,182-196.

Difrancesco, R. M., Meena, P., & Kumar, G. (2022). How blockchain technology improves sustainable supply chain processes: a practical guide. *Operations Management Research*, 1-22.

Ferreira de Araújo Lima, P., Marcelino-Sadaba, S., & Verbano, C. (2021). Successful implementation of project risk management in small and medium enterprises: a cross-case analysis. *International Journal of Managing Projects in Business*, *14*(4), 1023-1045.

Franceschetto S., Amico C., Cigolini R. (2022). The 'new normal' in the automotive supply chain after Covid". *Proceedings of the Summer School Francesco Turco*.

Franceschetto, S., Amico, C., Brambilla, M., & Cigolini R. (2023). Improving supply chain in the automotive industry with the right bill of material configuration. *IEEE Engineering Management Review*.

Gosling, J., Pero, M., Schoenwitz, M., Towill, D., & Cigolini, R. (2016). Defining and categorizing modules in building projects: an international perspective. *Journal of Construction Engineering and Management, 142*(11).

Harouache, A., Chen, G. K., Sarpin, N. B., Hamawandy, N. M., Jaf, R. A., Qader, K. S., & Azzat, R. S. (2021). Importance of green supply chain management in Algerian construction industry towards sustainable. *Journal of Contemporary Issues in Business and Government*, *27*(1), 1055-1070.

Kim, K., Lee, G., & Kim, S. (2020). A study on the application of blockchain technology in the construction industry. *KSCE Journal of Civil Engineering, 24* (9), 2561-2571.

Koskela, L., Vrijhoef, R., & Dana Broft, R. (2020). Construction supply chain management through a lean lens. *Successful Construction Supply Chain Management: Concepts and Case Studies*, 109-125.

Layaq, M. W., Goudz, A., Noche, B., & Atif, M. (2019). Blockchain technology as a risk mitigation tool in supply chain. *International Journal of Transportation Engineering and Technology, 5*(3), 50-59.

Mafundu, R. H., & Mafini, C. (2019). Internal constraints to business performance in black-owned small to medium enterprises in the construction industry. *The Southern African Journal of Entrepreneurship and Small Business Management*, *11*(1), 1-10.

Nanayakkara, S., Perera, S., Senaratne, S., Weerasuriya, G. T., & Bandara, H. M. N. D. (2021). Blockchain and smart contracts: A solution for payment issues in construction supply chains. *In Informatics*, *8*(2), 36.

Norese, M. F., & Carbone, V. (2014). An application of Electre Tri to support innovation. *Journal of Multi-Criteria Decision Analysi, 21* (1-2), 77-93.

Papadopoulos, G. A., Zamer, N., Gayalis, S. P., & Tatsiopoulos, I. P. (2016). Supply chain improvement in construction industry. *Universal Journal of Management*, *4*(10), 528-534.

Pero, M., Rossi, M., Xu, J., & Cigolini, R. (2020). Designing supplier networks in global product development. *International Journal of Product Lifecycle Managemen*, *13*(2), 115-139.

Pero, M., Sianesi, A., & Cigolini, R. (2016). Reinforcing supply chain security through organizational and cultural tools within the intermodal rail and road industry. *International Journal of Logistics Management, 27*(3), 816-836.

Pournader, M., Kach, A., & Talluri, S. (2020). A review of the existing and emerging topics in the supply chain risk management literature. *Decision Sciences*, *51*(4), 867-919.

Pozzi, R., Pero, M., Cigolini, R., Zaglio, F., & Rossi, T. (2019). Using simulation to reshape the maintenance systems of caster segments. *International Journal of Industrial and Systems Engineering*, *33*(1), 75-96.

Rossi, T., Pozzi, R., Pero, M., & Cigolini, R. (2017). Improving production planning through finite-capacity MRP. *International Journal of Production Research*, *55*(2), 377-391.

Rossi, T., Pozzi, R., Pirovano, G., Cigolini, R., & Pero, M. (2020). A new logistics model for increasing economic sustainability of perishable food supply chains through intermodal transportation. *International Journal of Logistics Research and Applications*, *24*(4), 346-363.

Saaty, T.L. (2008). Decision making with the analytic hierarchy process. *International Journal Services Sciences*, *1*(1), 83-98.

Shemov, G., Garcia de Soto, B., & Alkhzaimi, H. (2020). Blockchain applied to the construction supply chain: A case study with threat model. *Frontiers of Engineering Management*, *7*(4), 564-577.

Xu, J., Abdelkafi, N., & Pero, M. (2020). On the impact of blockchain technology on business models and supply chain management. *Proceedings of the Summer School Francesco Turco.*

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