Virtual Supply Chain Network Platform Design and Development for Crisis Response

Basak Tozlu(✉), Ali Akgunduz, and Yong Zeng

Concordia University, Montreal, QC H3G 1M8, Canada
basak.tozlu@concordia.ca

Abstract. The COVID-19 pandemic exposed the vulnerability of the Canadian economy on many fronts. When the demand for lifesaving equipment increased globally, the supply chain networks were broken by the direct involvement of other countries. The rising competition and interruptions caused Canada to face significant difficulties in global markets to secure critical medical equipment and protective materials. Not only hospitals and healthcare workers but also the public and patients had no access to the needed equipment even though companies and organizations in the country have the required capacity and resources. In such emergency times, Canada should produce the essential equipment within the country. We propose a four-step strategic product manufacturing system to ensure crisis response. The first and second steps are creating a manufacturing capability database of Canadian companies and a library of product families, respectively. These two steps should be completed before the crisis. The third step involves emergency need analysis, equipment design and forecasting. Finally, the fourth step is developing a virtual supply chain network platform through which the procurement, production, and transportation activities will be scheduled based on the capability database, product families library, and requirements analysis in the most efficient and economical way possible. The research utilizes various tools such as forecasting, optimization, simulation, multi-criteria decision making, and engineering design tools.

Keywords: Virtual supply chain network · Digital supply chain management · Crisis response · Emergency planning · Environment-based design (EBD)

1 Introduction

Even with well-planned and effectively operated supply chain networks, countries may still fail to access the lifesaving equipment during global crises due to foreign country interruptions or extreme competition worldwide. COVID-19 exposed the vulnerability of the Canadian economy on many fronts. Canada faced significant difficulties in international markets for securing the critical medical equipment and protective devices/materials, which were in high demand by Canadian hospitals, healthcare personnel and the public, especially during the early stages of the pandemic. When the need for lifesaving equipment increased globally, Canada found itself in conflict with other countries, including close allies. Existing supply chain networks were broken due to

K.-Y. Kim et al. (Eds.): FAIM 2022, LNME, pp. 502–509, 2023.
https://doi.org/10.1007/978-3-031-17629-6_52

high demand and the direct involvement of other countries. This research aims to fulfill the gap in the integration of various operations management tools to address a potential crisis in a low-cost, quick-to-analyze, and low-risk way.

Countries with the existing manufacturing capacities, such as China, Taiwan and Korea, overcame these challenges rapidly and provided the necessary medical devices and protective equipment to their people on time. On the other hand, countries with limited manufacturing resources/capacities faced significant challenges. Some equipment shortage problems could have been avoided if Canada had had the infrastructure to manufacture them locally. However, shaping the manufacturing capacity of a country according to highly probable future demands under possible global pandemics would significantly damage the competitiveness of the country in today's highly globalized world. While Canada is known to be a resource-based economy, manufacturing's contribution ($185 billion) to GDP was higher than the mining and oil and gas ($141 billion) in 2019. Today, several companies operating from Canadian soils focusing on the design, development, and manufacturing of various goods from aerospace to healthcare are competing in global markets successfully. Encouraging existing organizations to invest in products for which they do not have a competitive edge will diminish their competitiveness. Incubating the new companies to flourish in areas where Canada may have challenges during future pandemics will not bear economically sound companies. Such artificially formed companies will need substantial government subsidies to continue their operations in Canada.

A company's success lies in three basic business principles: survive, grow, and make a profit. When business conditions are not favorable to sustain these three business objectives, demanding or expecting Canadian companies to invest in the design, development, and manufacturing of specialized equipment such as medical, safety, security etc., will only increase Canada's competitiveness in the world. Hence, more creative solutions must be introduced to help Canada mitigate the risk of supply chain interruptions during future global crises. The COVID-19 conditions revealed a dilemma that Canada and many other countries face during global crisis: i) Countries need to be ready to absorb the impact of global crisis locally; ii) Organizations should provide goods and services in areas where they can stay competitive, survive in the highly competitive world market, grow, and make a profit. To overcome this dilemma, we propose to design a virtual supply chain network platform which relies on the capabilities of companies currently operating in Canada. However, their contributions are only triggered under emergencies to mitigate the risk of global pandemics. The remainder of the paper has a literature review in Sect. 2, challenges of the problem in Sect. 3, methodology in Sect. 4 and a conclusion in Sect. 5.

2 Literature Review

Technical challenges of the proposed project are i) extracting current manufacturing capabilities of Canadian companies; ii) identification of organizations with compatible manufacturing capacities; iii) designing and developing essential products; and iv) finally designing a supply chain system to manufacture and distribute the required products. In other words, the proposed platform considers the entire country of Canada as a single manufacturing system and schedules the production of goods as needed during emergencies with the minimum cost and maximum benefit to Canadians. Hence the literature summarized in this section focuses on computer-aided machining process planning [10], emergency transportation planning [16], and multi-plant manufacturing distribution systems [2].

The manufacturing capabilities of companies can be captured via two distinct methods. The first approach is conducting traditional surveys. Moreover, several private databases collect information related to the machining capabilities of various organizations in Canada. Both at the federal and provincial levels, governments also monitor the manufacturing capabilities of Canadian companies. As a second option, the manufacturing capabilities of Canadian companies can be extracted by studying their existing products. Most products sold include a user manual with detailed technical drawings. While manufacturing and design engineers can identify required machining processes from 2D and 3D geometries, several expert systems have been developed to determine the required manufacturing processes automatically. With the advances in computer technology, information processing, knowledge management, and deep learning fields, Computer-Aided Process Planning (CAPP) methods have become practical tools to determine the most efficient and economic processes to complete required machining operations [1]. The current trend is to develop knowledge generation-based technologies to model continually evolving CAPP methods [14]. Accordingly, in this project, we aim to utilize state-of-the-art CAPP methods and traditional survey techniques to populate a database for the currently available machining capabilities and their locations in Canada.

To minimize the cost and managerial challenges associated with the manufacturing of essential equipment during emergency situations, it is essential to select manufacturing companies with the highest compatibilities with the manufacturing requirements of these products. Identifying product families based on the manufacturing requirements may enable the achievement of such goals. In literature, product families are mainly discussed in the context of mass customization [8]. Companies that provide mass customized solutions to customers adopt modular manufacturing philosophies to optimize the usage of their manufacturing capabilities. They frequently use their partners to absorb the impacts of demand fluctuations. Hence, such systems require strong system integration. Greve et al. [5] proposed a module process-chart-based approach to coordinate both process and information flow within the organization. In their works, Heikal et al. [6] uses various indexing strategies such as the Commonality of Product Families (CPF) index and the Degree of Commonality Index (DCI) to build cross-industry product families to manage the manufacturing capabilities better and reduce manufacturing costs. As part of the proposed research project, we plan to adopt an indexation approach to study the commonality of Canadian-made products and establish a library of available product families.

The third and final stage of the proposed project is to design a supply chain network platform for manufacturing the selected essential products during crisis times like pandemics. The core idea of the proposed project is to consider entire Canada as a single manufacturing facility and schedule the production of goods based on the availability of manufacturing capacity, the manufacturing and transportation cost, compliance with health and safety rules and the desired distribution timeline. The proposed platform is a digital twin of the current physical supply chain. Literature provides an abundance of research work related to supply chain disruptions due to natural disasters. In their work, Bier et al. [2] provides extensive coverage of methodologies used for mitigating the impact of various types of disturbances on complex supply chain systems. Moreover, several organizations have started utilizing big data analytics to rapidly establish and continually adopt agile supply chain networks to gain a competitive edge in the fast-moving marketplace [4, 12]. Researchers have also studied the decision-making strategies to produce goods in multi-plant settings [13]. Moreover, research on intertwined supply networks [3] and cloud supply chains [7] have already showed promising results for the future of supply chains. A digital twin of a supply chain network is a digital replica of the real-life physical model with real-time information [3].

3 The Problem: Response to Crisis

During COVID-19, Canada felt a shortage of medical equipment such as ventilators, masks, and other protective products. When the shortage was felt, many government agencies, including research institutions, invited academics and private organizations to design and develop equipment in immediate need. Several academic institutions, including Concordia University, quickly responded to this call and designed various equipment, including ventilators. While some labs could produce small quantities of face masks for hospitals, no ventilator has been successfully developed and manufactured. Academic institutions quickly realized the scalability issue. Manufacturing face shields/masks using 3D printers were too slow, far from responding to the actual needs. Universities and other research institutions could not identify local partners to develop and test ventilators. Only a handful of large organizations with sufficient manufacturing capacities, such as the hockey equipment manufacturer Bauer was able to respond to the needs of the medical community (produced face shields for hospitals). Yet, Bauer's response was an ad-hoc solution, and most likely, it was the result of an individual's creativity within the organization. What Canada needs is a quick, almost automated conversion of its local manufacturing capacity to satisfy Canada's needs during a crisis when regular supply chain networks fail. In Bauer's case, they were able to make the entire face-shields in-house. Yet, it would be almost impossible for a standalone manufacturing company to design, develop and manufacture sufficient quantities of more complex products such as ventilators in such a short timeframe. On the other hand, sufficient manufacturing capability can be achieved by systematically coordinating the available resources in several independently run manufacturing companies. However, these organizations may not realize their potential to contribute as a part supplier for the manufacturing of essential products during pandemics. Despite having the manufacturing capabilities, their current product lines may not have obvious commonalities with the products in urgent need. To take full advantage of the existing production capabilities and utilize such capacity as a single manufacturing plant during emergency situations, an efficient strategy under the leadership of federal and local governments needs to be developed.

To ensure design and development of emergency equipment, an ontology-based methodology can be utilized. Environment-Based Design (EBD) is a three-step design methodology that generates effective design solutions [15]. The first step is environment analysis for the desired product. The second step is conflict identification, where major twines in the product environment are revealed. And finally, in the third step, which is named solution generation, design ideas are generated using the identified conflicts in the product environment. This design methodology is shown to provide efficient and comprehensive solutions in product and service design.

To manufacture enough essential products within Canada during global crises (any kind of product depending on the nature of the crisis: healthcare, military, heating, cooling, shelter, telecommunication, water sanitization etc.), we propose a four-step strategic system: i) Investigate manufacturing capabilities of Canadian manufacturing firms and creating a database based on manufacturing capability, reliability, quality, and availability; ii) Identify product families for the products currently manufactured in Canada; iii) Develop efficient manufacturing planning methodologies to identify the manufacturing needs of any type of product rapidly. Once the design, development, and manufacturing needs for products are determined, candidate companies with the compatible manufacturing capabilities are identified; iv) Finally, develop a virtual supply chain network platform to trigger production, transportation, and assembly of products when the need arises, and coordinate distribution of finished goods within Canada efficiently and economically.

4 Methodology

The development of the proposed research requires a four-stage approach.

4.1 Manufacturing Capability Database of Canada

The term "manufacturing capability" refers to i) availability of manufacturing equipment; ii) handled material types; iii) quality level; iv) reliability level; and v) quantity (manufacturing capacity). For instance, a specialized machine shop may have a lathe machine with steel forming capability with a maximum 30 cm/per minute machining speed. We propose three different solution techniques to populate the manufacturing capability database. First, surveys can be sufficient to capture the detailed manufacturing capability database of Canada. The second is to analyze current product lines. Using reverse engineering techniques and process scheduling algorithms, manufacturing equipment and the processes used to produce these products can be extracted. The third one is to analyze their webpages using web-crawler and natural language processing models. This step should be completed before the emergency crisis.

4.2 Library of Product Families

For the reasons stated earlier, we cannot expect companies to design various equipment to be produced for emergency situations. Hence, we propose such equipment be designed by research institutions such as universities and research centers in collaboration with government agencies such as healthcare, defense, transportation, telecommunication, energy etc., agencies and their emergency response teams. While reverse engineering from sample products may be a solution under extreme conditions, we expect most designs to be original and comply with international trade laws. Hence, a national database for Canadian patented design solutions for various types of products should be constructed. This database should include all kinds of products and product family information. As was the case in ventilator design, we anticipate universities and research institutions such as National Research Council Canada (NRC) to contribute to the generation of design solutions. Institutions are expected to deposit their design solutions to the national database. Through periodical updates, these product designs will be improved according to the changing conditions. In the case of an emergency, every stakeholder can grant access to the blueprints of any product in the library of product families. This step should be completed before the emergency crisis.

4.3 Requirements Analysis in Response to Emergency Crisis

Through analyzing the situations of the public emergency, needs and requirements for the critical equipment can be modelled and formulated. EBD methodology can be used to develop effective design solutions taking each component of the complex design environment into account. To know the amounts of production of each product, forecasting methods can be utilized. The blueprints of products and forecasted production amounts can be put in the virtual supply chain network platform as input to generate the procurement, production, and transportation solutions. This step should be completed as soon as possible after the emergency crisis.

4.4 Virtual Supply Chain Network Platform

Once product designs and production amounts are available and a manufacturing capability database for Canada is constructed, a virtual supply chain network platform will be developed. The basic idea is to identify manufacturing companies that have the capability of producing necessary subcomponents with the desired quality and quantity. Product families library and compatibility indexes will be used to identify candidate manufacturing facilities. Based on the current workload, availability of resources, and their products' contribution to the needs of Canadians during the pandemic, potential contributors to manufacturing the selected essential equipment will be identified. To match the capable companies with the forecasted need, multi-criteria decision-making (MCDM) methods will be used. When the match is found, scheduling algorithms will be utilized to find the timeline of the product procurement. When manufacturing tasks are distributed in a network of plants, the balance between centralized vs. decentralized management strategies becomes a vital factor. In addition to the design of the supply chain network, the most effective strategies to manage the resources and scheduling manufacturing tasks within individual organizations will be studied. This step should be completed as soon as possible after the emergency crisis.

Basically, each supply chain network for a product will have three tiers. At the first tier, there are raw material and labor procurement decisions. At this level, the demand forecast and the product requirements analysis are complete. The next step is to define the production requirements, including the raw material and labor needs. The transportation network for the procurement of raw materials will be designed and developed. At the second tier, there is production procurement. Once the potential companies are identified, the most appropriate ones based on time, cost, quality, and other product-specific criteria will be selected. At this stage, product design and process design are completed. Next, the manufacturing schedule, which includes production quantities and manufacturing start and end times at each manufacturing plant, are determined. The objective is to manufacture enough subparts in such a way that an uninterrupted supply to the demand locations is sustained until the impact of crises is over. The basic idea is to consider entire Canada as a single manufacturing plant and schedule the production of sub-components within this virtual plant with minimum cost and maximum efficiency to serve the Canadian public during the crisis. And finally, at the third tier, there is transportation procurement. At this level, the distribution of products will be modelled to ensure they reach the end-user or the retailers in a timely and cost-efficient manner. If needed, distribution channels will be included. The main goal is to find the best distribution model.

4.5 Optimization and Simulation

To realize these objectives, operations research, data analytics, forecasting, optimization, and simulation tools will be utilized. Based on the severity and the impacted areas, a different set of manufacturing companies may be selected. Moreover, depending on the potential demands, the logistic network design would vary significantly. Hence, stochastic optimization [9] and simulation-based optimization methods [11] will be utilized to help decision-makers study alternatives.

5 Conclusion

For Canada to protect its citizens in the next global pandemics, an adaptive virtual supply chain network must be built and continually updated for manufacturing lifesaving products when in need. The proposed platform requires close collaboration between universities, governments, local industry, and the supervisor stakeholders (such as healthcare, defense, education, transportation, and energy systems). In this framework, universities and other research labs continually design and develop lifesaving equipment. An intelligent data-analytic model identifies potential part suppliers and evaluates their capabilities to manufacture lifesaving equipment. Under emergency situations such as COVID-19, the proposed platform is waken-up, probably by the government, to produce and deliver their designated parts to potential assembly plants. Such a system will enable universities and research labs to scale up easily to manufacture enough lifesaving products and deliver them to end-users. The proposed virtual supply chain network platform enables Canadian companies to continue competing in the world with product lines that have a competitive edge during non-emergency times, yet the country will be ready to face future challenges due to various kinds of disturbances to the existing supply chain networks.

References

1. Behandish, M., Nelaturi, S., Verma, C.S., Allard, M.: Automated process planning for turning: a feature-free approach. Product. Manufact. Res. **7**(1), 415–432 (2019)
2. Bier, T., Lange, A., Glock, C.H.: Methods for mitigating disruptions in complex supply chain structures: a systematic literature review. Int. J. Prod. Res. **58**(6), 1835–1856 (2020)
3. Dolgui, A., Ivanov, D., Peron, M., Sgarbossa, F.: Expected trends in production networks for mass personalization in the cloud technology era. In: Design and Operation of Production Networks for Mass Personalization in the Era of Cloud Technology, pp. 13–37 (2022)
4. Dubey, R., Gunasekaran, A., Childe, S.J.: Big data analytics capability in supply chain agility: The moderating effect of organizational flexibility. Manag. Decis. **57**(8), 2092–2112 (2019)
5. Greve, E., Rennpferdt, C., Krause, D.: Harmonizing cross-departmental perspectives on modular product families. Proc. CIRP **91**, 452–457 (2020)
6. Heikal, E.A., El-Kharbotly, A.K., El-Beheiry, M.M.: A proposed index to assess commonality among aircraft product families. IOP Conf. Ser. Mater. Sci. Eng. **610**(1), 012082 (2019)
7. Ivanov, D., Dolgui, A., Sokolov, B.: Cloud supply chain: integrating industry 4.0 and digital platforms in the "supply chain-as-a-service". Transp. Res. Part E Logist. Transp. Rev. **160**, 102676 (2022)
8. Jiao, J., Tseng, M.M.: A methodology of developing product family architecture for mass customization. J. Intell. Manuf. **10**(1), 3–20 (1999)
9. Juan, A.A., et al.: A review of the role of heuristics in stochastic optimisation: from metaheuristics to learnheuristics. Ann. Oper. Res. 1–31 (2021)
10. Marri, H.B., Gunasekaran, A., Grieve, R.J.: Computer-aided process planning: a state of art. Int. J. Adv. Manufact. Technol. **14**(4), 261–268 (1998)
11. Mourtzis, D.: Simulation in the design and operation of manufacturing systems: state of the art and new trends. Int. J. Prod. Res. **58**(7), 1927–1949 (2020)
12. Nguyen, T., Li, Z., Spiegler, V., Ieromonachou, P., Lin, Y.: Big data analytics in supply chain management: a state-of-the-art literature review. Comput. Oper. Res. **98**, 254–264 (2018)
13. Olhager, J., Feldmann, A.: Distribution of manufacturing strategy decision-making in multi-plant networks. Int. J. Prod. Res. **56**(1–2), 692–708 (2018)
14. Yang, Y., Hu, T., Ye, Y., Gao, W., Zhang, C.: A knowledge generation mechanism of machining process planning using cloud technology. J. Ambient. Intell. Humaniz. Comput. **10**(3), 1081–1092 (2018). https://doi.org/10.1007/s12652-018-0779-2
15. Zeng, Y.: Environment-based design (EBD): a methodology for transdisciplinary design+. J. Integr. Des. Process. Sci. **19**(1), 5–24 (2015)
16. Zheng, Y.J., Ling, H.F.: Emergency transportation planning in disaster relief supply chain management: a cooperative fuzzy optimization approach. Soft. Comput. **17**(7), 1301–1314 (2013)