Economic Aspects of a Resource Sharing Manufacturing Network under Turbulences

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Abstract: Nowadays, manufacturing companies face more difficulties than ever. Unrest in global supply chains triggered by fluctuating customer demand, raw material shortages and crises (Covid pandemic, global warming, wars) complicate the utilization of production resources necessary for economic success. Also, the rapidly changing environment causes existing production plans to be adapted, which results in order changes, causing additional costs for manufacturers. One solution to cope with these problems is cooperation and sharing resources: requesting capacity from partners when having shortages and offering them temporarily in case of excess capacity.

In this paper, a platform-based resource sharing mechanism is investigated from the economic perspective. In the mechanism, requests and offers are matched by a central platform applying a complex matching logic. The platform provides valid alternatives based on the incoming orders that the requesting company can choose from. Companies are rating each other's performance after each interaction based on delivery accuracy; choosing between resource offers is made based on the cumulated rating about the offeror and the price of the offer.

Within this paper, the aim is to investigate the resource sharing mechanism from the economic point of view based on an approach to the responsiveness of a supply chain structure to turbulence, to support decision-makers trying to cope with unexpected changes. For this purpose, here the mechanism is briefly introduced, and basic concepts about turbulences in supply chains are also presented. Cost types related to resource sharing manufacturing companies are distinguished, and the model is validated with agent-based simulation. A simulation experiment is performed to investigate the use-case of outsourced jobs having different price levels. Based on the experiment, it can be concluded that there is a price level limit in such a resource sharing federation, under which it is worth it to collaborate with partners by outsourcing certain jobs to them.

Keywords: resource sharing; turbulence, financial impact

1. Introduction

Established, supposedly efficient, global supply chain structures collapsed under the changed environment of COVID-19. Volatile markets continue to complicate manufacturing companies' supply chain structures. In the context of these challenges, easily changeable supply chain structures and cooperation methods are being discussed, promising better performance, especially in uncertain market environments, compare Wiendahl et al. 2007; Wiendahl 2002; Koren et al. 1999; Bauernhansl et al. 2012. However, the financial benefits of the changeability are difficult to assess, and the optimal system setup (required changeability degree) is therefore hard to determine.

The idea of collaboration and sharing resources through an online platform was proposed by the International Electrotechnical Commission 2015. As mentioned in Kaihara et al. 2017, Build-to-Order (BTO) companies often keep extra capacities to be able to meet order deadlines; for these companies, crowdsourcing can be an effective way to reach a high resource utilization level. Collaborating via resource sharing can also be a solution in a highly uncertain environment, as outsourced resources can be considered as a temporary extension of the company. These resources can be used when the company has to change its production plans due to some turbulences, e.g., order change. Similarly, if the changes result in unused resources, through a platform it is also possible to offer the resources to be used by other partners – resulting in a higher resource utilization level.

The above-mentioned concept has already been investigated by the authors. In Szaller et al. 2020a, a direct exchange-based resource sharing concept was introduced and tested with agent-based simulation, in Szaller et al. 2020b the basics of the platform-based mechanism were presented, and in Szaller and Kádár 2021 the two approaches were compared by considering advantages and disadvantages, and performing simulation experiments. In these mechanisms, collaborating partners who are members of a resource sharing federation receive a continuous order stream from customers, and they request or offer resources to each other, depending on the requirements of the jobs they are planning to complete. Requesting companies choose from resource offers based on their price and the rating of the offeror: the basis of this rating is trustfulness, and it is calculated based on delivery accuracy of the offeror. As discussed in the above-mentioned papers, this resource sharing concept could be useful for companies having resources that can be used more generally (e.g. 3D printers, laser cutting machines) and also for ones having expensive, specific resource types, when trying to utilize them as much as possible.
Resource sharing mechanisms, in general, have been investigated from different aspects in the literature: in Scholz-Reiter et al. 2011, the robustness of capacity allocation was studied in order to find an optimal way of outsourcing resources in a production network with the desired robustness. Kádár et al. 2018 proposes a resource sharing algorithm for federated production networks and validate the concept with agent-based simulation. Chida et al. 2020 investigate the strategyproofness of resource matching in crowdsourced manufacturing.
However, *economic aspects* of resource sharing under a turbulent environment were not investigated previously. From this point of view, the structure of this partnership is similar to the supply chains (see Pettersson and Segerstedt 2013, Ustundag and Tanyas 2009, Whicker et al. 2009), but it is also different because the participants are on the same level of value creation; they are collaborating and competing with each other at the same time. This paper applies an approach, where the financial impact is evaluated based on the responsiveness of a supply chain structure to turbulences. To validate the model and investigate the effect of the price of outsourced jobs an agent-based simulation model is introduced in brief, and simulation experiments are also performed.

2. Turbulence within Resource Sharing Networks

Turbulence was first described experimentally by Hagen in 1854 and later by Reynolds in 1883 with the so-called color thread experiment, see Reynolds 1883. Since the middle of the 20th century, a wide variety of authors have endeavoured to analogize the term "turbulence" from physics to the problems of business science, see Mintzberg 1994. This paper uses the concept of turbulence germs from Wiendahl 2007, where five cause groups for turbulence are distinguished: variations, fluctuations, plan adjustments, inconsistencies and deviations. But the mere existence of these turbulence germs is not sufficient to generate turbulence rather the ratio of requirements to capabilities is decisive for the occurrence of turbulence. This highlights the necessity of changeable structures such as resource sharing in turbulent markets.

In order to show the advantages of being a part of a resource sharing network, this paper evaluates the financial impact under different scenarios. Therefore, the responsiveness of this kind of collaboration structure to turbulence is evaluated from the financial aspect. Thus, two cost types are distinguished: laminar and turbulent costs, see Fig.1a. **Laminar costs** are costs to adjust system design and are independent of the occurrence of a turbulence germ. They provide the fundamental ability to avoid turbulence before it occurs. **Turbulence costs** are the costs incurred directly or indirectly by the occurrence of turbulence germ. They are thus dependent on the occurrence of a turbulence germ. Turbulence costs are therefore the costs generated by disturbances in the supply chain processes, see Fries and Bauernhansl 2022a. For example, costs caused by changing order streams, like: inventory devaluations, special runs, overtime, holiday surcharges, underutilization, setup costs, downtime costs, additional costs of the procurement, higher overhead costs by rescheduling, contract penalties, rework, loss of sales, and many more.

Based on this cost differentiation, the system's performance is determined based on the overall total cost (laminar + turbulence costs), as shown in Fig. 1b. Thus, a changeable system has higher laminar costs based on e.g. higher capital and operating costs, but lower turbulence costs in case of unforeseen turbulence (e.g. supply issues). A rigid (non-changeable system), on the other hand, has low laminar costs, but very high turbulence costs in the event of turbulence.

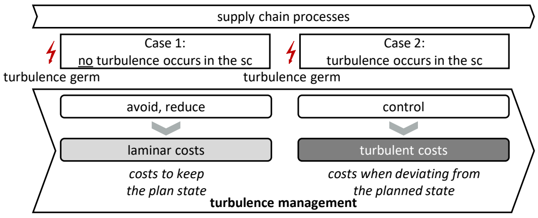

Figure 1a. Difference between laminar and turbulence costs, compare Fries and Bauernhansl 2022b

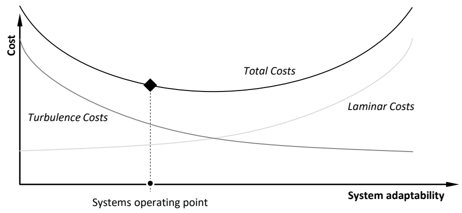

Figure 2b. Trade-off between rigid and flexible systems in terms of turbulence and laminar costs

Within this paper, the responsiveness of the resource sharing network to turbulences is investigated using laminar and turbulence costs. In the following, the individual cost types which are calculated within the simulation model are broken down, and the relationships between the determinant and the cost level are described.

3. Economic Aspects of the Resource Sharing Network

In order to assess the economic effect of the resource sharing network, a quantitative cost break down approach is taken, which determines each process step in the overall production process, including indirect areas and assigns costs to them. As mentioned before, cost structures in connection with supply chains can be found in the literature. However, these structures often are adapted to the specific use cases and also miss important aspects of resource sharing. Thus, a specific cost model for the resource sharing community is developed within this paper. The different cost types applied within this paper represent:

Manufacturing costs

These include all the costs related to manufacturing the requested number of products. The company has to pay for the materials in case of each manufactured product (unit-level costs), and also for the labour and the machine costs, which are proportional to the manufacturing time. Batch-level and order-level manufacturing costs can arise too (e.g. setup and changeover costs), and facility sustaining costs can also be mentioned here.

Administration costs

Administration costs can be separated into two main parts in the presented resource sharing model: management costs and order consolidation costs. Management costs in the introduced case mean all the costs that a company pays to the platform: the one-time entrance fee, the regular participation fee, and the cost of sending and accepting requests and offers. The latter is necessary because otherwise, companies would send fake requests to the platform, to try to create a competitive advantage from the answers (e.g. trying to learn rare manufacturing equipment types, free resources of the others). Other administration costs, called order consolidation costs are incurring for the company that is managing all the jobs in an order. This cost type means all the costs in connection with managing the outsourced and insourced jobs, communicating with the customer, etc. In case of turbulences in the original order, administration costs naturally also increase, and cooperation with partners might be needed to satisfy the customer needs.

Inventory costs

Inventory costs can occur when storing WIP products during production (buffers and supermarkets in the production hall). Warehouse costs can also be considered here: operating with a higher lot size, these costs increase (waiting until the whole lot is ready for delivery). In case of early job completion, the products also have to be stored in the warehouse; thus, this cost is highly dependent on possible deviations from the original production plan.

Distribution costs

Distribution costs cover transportation costs (between customers and manufacturers) and transportation consolidation costs (between participants, in case of outsourced jobs). In general, distribution costs are dependent on the transportation mode: e.g. the transportation cost of one product could be lower when choosing transportation by train rather than by truck. Possible transportation types are dependent on the size of the lot to be transported: the "per unit" transportation cost is lower when sending, e.g. a full container to the customers. However, cheaper transportation types are usually slower: companies have to consider the delivery deadlines, also. To decrease distribution costs, it is suggested to have a shipment generation system where costs can be calculated, and the above-mentioned aspects could be investigated in order to operate a system that can handle possible disturbances.

4. Simulation Experiments

4.1 Simulation model

To investigate the financial model for the resource sharing federation, some use cases were created using agent-based simulation. The model is implemented in AnyLogic simulation software, where both the companies and the platform are modelled with agents. During model running, the companies are receiving a continuous stream of order changes that triggers performing several pre-defined functions: e.g., checking their capability to complete the affected job, composing and sending offers/requests, matching logic of the platform, etc. The platform stores the received and not matched requests and offers in its database, which is continuously updated during the simulation run.

Table 1. summarizes the main input parameters for the simulation experiments. As the instantiation of the cost functions is not the focus of this paper, not all parameters are shown in detail as the aim is not the introduction of a detailed cost model but to investigate the capability of the resource sharing concept to handle disturbances on a high level. However, for the parameters determined by using a truncated normal distribution, the mean and sigma values are included in the table (for the constant ones, sigma is 0). In these cases, the difference between the lower and upper bounds of the distribution from its mean is sigma/2. Regarding the partner selection, we expect the best results if companies of the same region and with a similar product portfolio take part in a resource sharing cooperation. This way, both transportation and machine setup efforts are minimized and lead to fewer additional costs Becker and Stern 2016. Thus, in the model, 10 companies – located virtually in Hungary – were implemented, and all of them had 16 different resource types out of the required 20 that were used to compose the order changes. One order change included 3 job types that can require different resource types to complete. The resource type for a job was chosen randomly from the 20 possibilities.

As indicated in Table 1, each company received an order change every model time unit that included 3 jobs, consisting of, on average 200 products (with a high sigma value, meaning that a negative change is possible: some of the already booked resources become free) and requiring 4 pcs of resources (e.g. 3D printers) for, in average 12 time units. The platform could combine a maximum of 3 offers to fulfil the requirements of a request in order to reduce administrative and logistics costs. The planning horizon, i.e., the length of the time interval for which the companies could offer their resources in advance, was 40 time units.

Regarding the cost parameters, the entrance fee that had to be paid when entering the federation was 10 monetary units, the regular fee was 5; the latter was paid after every 20 time units. The experiments were run for 1000 time units. In the case of outsourced jobs, it was assumed that the manufacturing cost per product for the outsourced jobs was 90% of the insourced ones, as a baseline – meaning the partner companies work less expensively, as outsourcing in reality often happens towards a company whose core business is the specific job type and thus can operate its resources in a more efficient way.

Table 1. Input parameters for simulation experiments

Parameter	Mean	Sigma	Unit
General simulation parameters			
Order change interarrival time	1	0	tu*
Length of time required to complete order change	12	6	tu
Resource quantity required to complete order change	4	2	pcs.
Number of products in one order	200	300	pcs.
Number of jobs in one order	3	0	pcs.
Max. number of offers to be combined by the Platform	3	0	pcs.
Planning horizon	40	0	tu
Probability of cancelling an order (for all companies)	2	0	%
Simulation time	800	0	tu
Cost parameters			
Entrance fee to join the federation	10	0	mu**
Regular fee for federation members	5	0	mu
Regular fee payment time interval	20	0	tu
Initial capital for companies	100	0	mu
Manufacturing cost per product for the outsourced jobs compared to insourced ones	90	0	%
Profit margin for all companies	10	0	%

*time units, **monetary units

4.2 Experiment – Investigating the price of outsourced jobs

In real industrial environments, companies outsource a job only if the manufacturing cost of the job is that much less expensive to cover the additional management, transportation consolidation and inventory costs. Of course, in some cases, it is reasonable to outsource an order even if the outsourced costs are higher, e.g. if the in-house capacity to fulfil the customer order is not available. But the additional cost of the outsourcing step should not be higher than the contribution margin of the outsourced step.
In the following experiment, a federation member named Company 1 was tested, and the price levels of the outsourced orders were investigated. Here it was assumed that companies outsource a job in any case when they cannot complete an order using their own resources, without regarding the financial balance of doing so. Figure 3 depicts that in the case of a ratio of 90%, it is worth it to be a member of the federation and outsource orders, but as the ratio increases, the company becomes uneconomical. If the partners are using the same unit prices as the resource requester company (100%), depending on the contents of the orders, there are time intervals where the income is positive (higher number of insourced jobs), but in other cases, the income is negative (higher number of outsourced jobs, loss is created). In such a resource sharing federation, depending on the extent of the additional costs, a company could find the specific cost level where it is reasonable to outsource orders, taking the loss of trustfulness towards the customers into consideration.

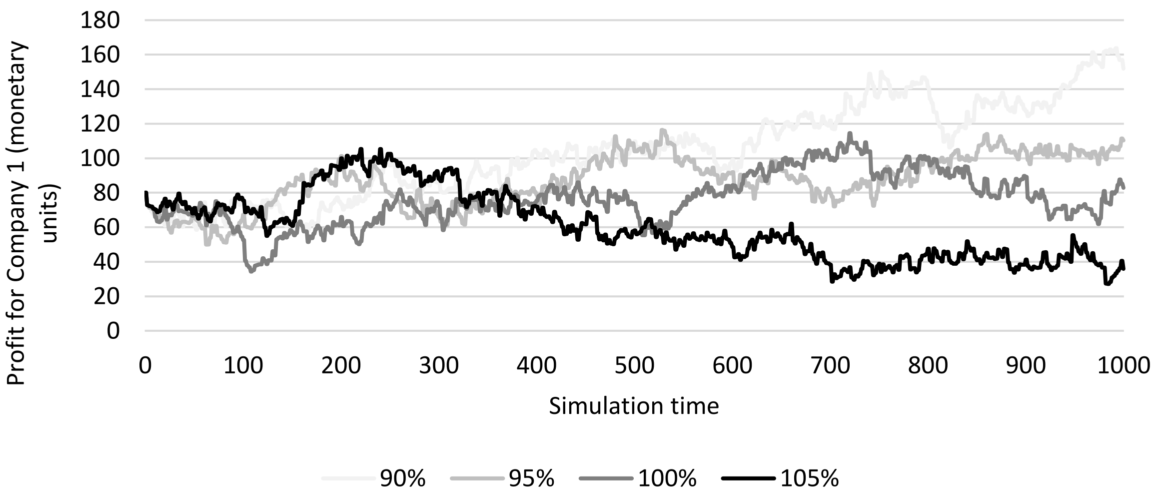

Figure 3. Effect of price of outsourced jobs

5. Conclusion and Outlook

Driven by complex supply networks and reoccurring disruptions like the corona crisis, supply chain resilience and flexibility have gained increasing attention. Nowadays the aim for manufacturing companies is to increase performance in highly uncertain environments and therefore reduce overall total cost of their supply network. As a key enabler, collaboration among the network participants was identified and has since been incorporated into different supply network concepts. One promising concept in terms of a holistic collaboration approach is platform-based resource sharing. Even though this concept has been investigated from a technical standpoint, a financial investigation was yet missing.

Therefore, this paper applies a financial model for the resource sharing network, in order to investigate its financial behavior under turbulence. Within this network, the manufacturing companies are collaborating by sending requests (in case of resource shortage) and offers (in case of resource surplus) to a central platform to match them, this way utilizing their resources and exploiting their business opportunities on a higher level.

The financial model consists of the description of costs related to resource sharing, such as manufacturing, administration, inventory and distribution costs. By using agent-based simulation, the impact of the price of outsourced jobs is investigated to see the performance of resource sharing when having disturbances in customer orders. With simulation experiments, it is shown that the price of outsourced jobs strongly affects the incomes of the participants and there is a limit for the price above which it is not worth outsourcing.

In future works, the model is planned to be extended with dishonest companies who are trying to influence the resource sharing mechanism by sending fake offers, and could learn using artificial intelligence algorithms based on the responses received from the Platform (e.g., what resource types are rare in the federation, and offer them more expensively). Another future direction is to apply a more complex multi-criteria decision-making algorithm in the decision-making and assignment processes.

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