What Industry 4.0 Means for Just-In-Sequence Supply in Automotive Industry?

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Abstract. The available and future solutions for the digital transformation and use of exponential technologies indicate revolutionary changes in the whole supply chain of manufacturing and service processes. The vertical networking of smart manufacturing systems and the horizontal integration of value-making chains led to a new supply paradigm based on hyperconnected global logistics systems. The goal of the paper is to identify challenges of just-in-sequence supply in the automotive industry from the aspect of Industry 4.0 solutions. The authors introduce readers in both the Industry 4.0 paradigm as well as the just-in-sequence supply. Defining the conception of cyber physical logistics systems (CPLS) authors describe the I4.0 solutions based relations between just-in-sequence supply and Reference Architecture Model Industry 4.0 (RAMI 4.0). The main goal is to define challenges and impacts of Industry 4.0 paradigm on just-in-sequence supply.

Keywords: Industry 4.0 · Just-in-sequence · Logistics · RAMI 4.0
Supply chain

1 Introduction

Within just-in-sequence supply chain developments one of the most important issues is the implementation of Industry 4.0 solutions in automotive industry. The utilization of technological and logistic resources has become a key challenge for the logistics sector, especially in the field of just-in-sequence supply chain.

The Industry 4.0 solutions are related to development of industrial processes, especially coordination of just-in-sequence supply chain. The available solutions use exponential technologies in the whole supply chain of manufacturing and service processes. Smart manufacturing systems and the value-making chains led to a new supply paradigm based on hyperconnected global logistics systems. The complexity of supply chain processes related to hyperconnected global supply requires up to date methods to find near-optimal parameters for the operation of the processes.

Due to the large amount of researches on the related streams the most relevant scientific results have to be summarized before elaborate the model, algorithm and solution.

The aim of this paper is to identify challenges of just-in-sequence supply in the automotive industry from the aspects of Industry 4.0 smart solutions. Second goal of paper is to define models to optimize the just-in-sequence supply chain between two tiers'

K. Jármai and B. Bolló (Eds.): VAE 2018, LNME, pp. 226–240, 2018.
https://doi.org/10.1007/978-3-319-75677-6_19

related costs. This paper is organized as follows: Sect. 2 presents a literature review, which summarizes the research results related to I.4.0 aspects of just-in-sequence supply chain operation. Section 3 shows just-in-sequence supply between two tiers focusing on operation cost. Conclusions and future research directions are discussed in Sect. 4.

2 Literature Review

Since our study embraces three related research streams, namely just in sequence supply, Industry 4.0 and Reference Architectural Model Industry 4.0, we provide a brief review on each stream before to present our approach.

2.1 Industry 4.0

Industry 4.0 contains a technological revolution of manufacturing and logistics systems, where digital and physical production systems enable implementation of smart production and logistics [1]. Aspect of Industry 4.0 is very important for logistics, because logistic solutions support several services for the players of the supply chain. Logistics must provide additional logistic tasks according to the seven rules of logistics: the right product, in the right quantity, with the right quality at the right place, at the right time, at the right costs for the right customer. As the development of logistics shows the optimization of self-contained features developed to the optimization of global hyperconnected networks [2].

Logistics has undergone many significant changes in the last period. For example, there is increasing knowledge requirements with new global technology implementation [3]. Several books and articles have been published which introduce several reflections regarding requirements and issues enabling organizations to be more efficient, and well operated in Logistics 4.0 context [4].

Industry 4.0 touches the entire supply chain management, intelligent manufacturing, methods, and Logistic 4.0. New business model and structures are required in the fields of Cyber-Physical Production Systems (CPPS). CPPS uses the automated information and communication network. The application of new technological elements and methods becomes possible even with more complex systems. Smart production tools align processes to increase efficiency, reduce resources, utilize capacities, reduce lead times and improve quality. The logistic tendencies and challenges are representing drastically changes in logistic domain. The tendencies, such as supply chain, customer demand and logistic service sector, are analyzed with reasons and driving focus.

Industry 4.0 refers to automation of industries, because the exchange of data takes place between logistics and the supply chain [5]. The main focus of Industry 4.0 is laid on the fusion of the physical and the virtual area, and new concepts are also required for managing tasks in the context of Industry 4.0 [6].

In the future, logistics will be supported by logistics assistance systems such as Smart Logistics, and Digitization of the supply chain [7].

There are an enormous number of reasons to evaluate the environmental performance of products. Design of environmental aspect is an important task of intelligent manufacturing. New concepts are available for manufactures to improve flexibility and competitiveness with application of intelligent manufacturing technologies. Small-scale Intelligent Manufacturing Systems (SIMS) solves a supply chain issues [8]. European research project also focused for smart manufacturing supply chains, called NIMBLE platform (a microservice architectural approach) support a core business and B2B market [9].

Global competition and increased product variety has collectively forced the manufacturing processes and their logistics service provider. It is a key challenge to strength the cooperation and networking through hyperconnected global logistics system. Supply Chain Management improving efficiency and quality of distribution and production processes [10] by applying recent trends such as Internet of thing [11]. It can improve in-, and outbound operations, because the system experiences are better organized and optimized [12]. Manufacturing and logistics researcher's also focus on developing intelligent systems to stay competitive and respond and handle a market changes [13]. There are available frame of the revenue-sharing contract to ensure a more balanced operation and profit among the supply chain members [14].

2.2 Just-In-Sequence Supply

Just-in-sequence (JIS) supply is mentioned as a reinterpretation of Just-in-Time (JIT) principles. JIS is researched from the JIS optimization point of view, JIT strategies and researches in the field of supply chain. JIS supply integrates the advantages of the supplier processes and the classic auditing [15], and has a great impact on the improvement of efficiency and availability of logistics processes and services. JIS/JIT solutions are supporting suppliers to focus on their core business. The JIS supply philosophy is a core part of lean thinking. The aims of Toyota production system (TPS) are to serve world quality products, reduce operation costs [16], and satisfy customer needs. JIS supply strategy is one of the most popular lean tools. There are several advantages such as controlling costs, reducing risk of supply chain and supporting third-party logistics (3PL).

Several books and articles have been published which address the available methods including analytic and heuristic algorithms, model to solve logistic issues in supply chain management domain, multi-purpose optimization and simulation. The complexity of supply chain networks led to an increased usage of simulation tools. Supply chain processes have a great complexity in the case of linked manufacturing systems, and new methods were developed for the efficient simulation of structured supply chain models [17].

Several applications can be found in the literature, especially in the automotive industry. Genetic algorithm was obtained and applied to evaluate different decisions principle to reduce risks of manufacturing [18]. In the assembly line, the intra plant transport system is improved by the new transportation technology with two operational modes to reduce operational expenses [19]. Researchers also analyzed supply scheduling processes with line-integrated supermarkets [20]. Discrete event and agent-based simulation methods are described for the simulation of delivery processes in automotive industry [21]. The automakers regard to reduce minimal cost of operation and increase competitiveness [22]. The BMW group allocated time slots to dynamic control system, which optimize control traffic sequences. It can integrate the transport shippers and truck identification processes [23]. JIS solutions are also used in enterprise applications for a real-time business process. Multi-agent system framework is designed to monitor and control dynamic production flows [24].

As previous studies shows, in the field of just-in-sequence supply there are different design aspects to be taken into consideration like routing [25], outsourcing [26], integrated design of facility location and assignment of resources [27] or resource scheduling [28]. The just-in-sequence supply is a suitable solution both for traditional manufacturing processes and special technologies, like blending [29].

2.3 Reference Architectural Model Industry 4.0

The basic motivation of the development of RAMI 4.0 was to propose a framework for technical maintenance systems in the context of a cyber-physical production environment, which has a great impact on the in-plant operation [30]. Hyperconnected Production and Service Systems (HPSS) are the most important driving forces behind the transformation of industrial production and service processes towards "digital factory and digital services of the future" in the context of Industry 4.0 paradigm. Security is a major concern for such systems as they become more complex, intelligent and interconnected with technical, logistics and human resources. Based on the RAMI 4.0 standard practical approach was proposed to establish a security viewpoint in Cyber-Physical Production Systems [31], but the same security control and architecture can be applied for HPSS. The RAMI 4.0 reference architecture provides common and consistent definitions in I4.0 and can be described as a special architecture model of the generic Smart Grid Architecture Model [32].

As surveys and studies show, there is an evident gap between the requirements supported by the current automotive manufacturing execution systems (MES) and the requirements proposed by industrial standards. Derived the requirements from the needs of ISA-95 and ISA-88 standards using Systems Modeling Language (SysML), the RAMI 4.0 standard seems to be a suitable direction to eliminate this gap [33]. RAMI 4.0 reference model makes it possible to integrate Smart Factories, Cyber-physical systems, Internet of Things, and Internet of Service with the aim of extended flexibility, capacity, capability and availability. In intelligent manufacturing systems, especially in the automotive industry FDI, AutomationML and OPC Unified Architecture standards can be used by RAMI 4.0 [34].

The existence of manufacturing and service companies is associated with business risk through the operation of IT solutions. This is especially true in the case of networking companies. Within the frame of I4.0 new security challenges have to be solved to handle a wide range of risks, like hacker attacks, data theft or manipulation, so RAMI 4.0 development needs more attention from the point of view security management [35]. Cloud-based monitoring of production is a brand-new solution of I4.0 solutions. RAMI 4.0 makes it possible to analyses the cyber security of hyperconnected systems to identify protection demands and find the suitable countermeasures [36].

The Resource Description Framework (RDF) is a suitable tool to represent RAMI 4.0 and focuses on interoperable communication and machine comprehension in

Industry 4.0, but the RAMI 4.0 has a significant impact on the physical system, like materials handling or manufacturing [37].

2.4 Consequences of Literature Review

More than 80% of the related articles were published in the last 3 years. This result indicates the scientific potential of this research field including the problems of just-in-sequence supply in interconnected logistic systems. The articles that addressed the I4.0 domain is focusing on IT related problems and only a few of them aimed to identify the logistic aspects from design and operation point of view of supply chain. Therefore, the design aspects of hyperconnected supply chain processes still need more attention and research, especially in the case of just-in-time and just-in-sequence supply. It was found that just-in-sequence supply is important for automotive industry. According to that, the focus of this research is the analysis of just-in-sequence supply from the Industry 4.0 paradigm point of view.

3 Industry 4.0 in Just-In-Sequence Supply Domain

Within the frame of this chapter four different models of assignment of just-in-sequence supply between two tiers are introduced:

- with direct sequencing and shipping from lower tier supplier;
- with direct sequencing and shipping from connected lower tier suppliers;
- with indirect shipping through a service point from lower tier suppliers and the sequencer is the manufacturer;
- through a service point from hyperconnected lower tier suppliers.

3.1 Scenario 1: Supply Between Two Tiers with Direct Sequencing and Shipping from Lower Tier Supplier

The first model represents the just-in-sequence supply chain in case of two tier supply chain, where all suppliers can deliver parts for each manufacturer (see Fig. 1). This model represents a traditional just-in-sequence supply chain, which is not suitable for hyperconnected supply chain processes. The suppliers have the required amount of product for each manufacturer, so no assignment is needed.

The model framework of just-in-sequence supply between two tiers with direct sequencing and shipping from lower tier suppliers has n suppliers that produce the needs for m different manufacturers. The decision variables define the decisions to be made. In this scenario the following decisions must be made: (1) assignment of suppliers to manufacturers; (2) assignment of suppliers to sequences. With this in mind, we can define the following decision variable:

- $x_{i,l,j}$ is the assignment matrix of manufacturers, suppliers and sequences, where $i = 1 \ldots m$, $l = 1 \ldots n$ and $j = 1 \ldots p$.

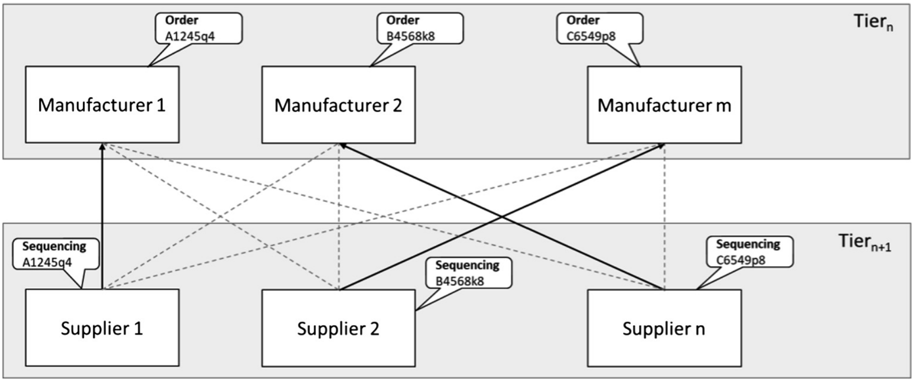

Fig. 1. Model of just-in-sequence supply between two tiers with direct sequencing and shipping from lower tier suppliers.

The objective function of the problem describes the minimization of the operation costs of supply chain:

$$c_1 = \sum\nolimits_{i=1}^{m} \sum\nolimits_{l=1}^{n} \sum\nolimits_{j=1}^{p} x_{i,l,j} \left(c_{l,i}^{SUP}(j) + \sum\nolimits_{k \in \Theta_j} c_{l,k} \right) \rightarrow min., \tag{1}$$

where

- $c_{l,i}^{SUP}$ is the supply costs from the supplier l to manufacturer i,
- $c_{l,k}$ is the price of product k by supplier l,
- Θ_j is the set of products assigned to sequence j.

As constraint we can define the availability of products. The availability can take into consideration from amount and time point of view:

$$\mathrm{q}_{i,j,k} \leq m_{l,j,k} \; \forall k(i,j,l = const) \wedge t_{l,i,j}^{A} + t_{l,i}^{SUP} \leq \tau_{i,j}, \tag{2}$$

where

- $m_{l,j,k}$ is the available amount of product k for sequence j at supplier l,
- $\tau_{i,j}$ the required availability time of sequence j at manufacturer i,
- $t_{l,i,j}^{A}$ is the availability time of sequence j for manufacturer i at supplier l, which can be calculated as follows:

$$t_{l,i,j}^{A} = \max\nolimits_{k \in \Theta_j} t_{l,i,j,k}^{A}, \tag{3}$$

– $t_{l,i}^{SUP}$ is the supply time of manufacturer i from supplier l, which can be calculated as follows:

$$t_{l,i}^{SUP} = t_{l,i}^{T} + t_{l,i}^{P} + t_{l,i}^{S} + t_{l,i}^{L} + t_{l,i}^{Q} + t_{l,i}^{W}, \qquad (4)$$

where

– $t_{l,i}^{T}$ is the time of transportation,
– $t_{l,i}^{P}$ is the time of packaging,
– $t_{l,i}^{S}$ the sequencing time,
– $t_{l,i}^{L}$ is the loading time,
– $t_{l,i}^{Q}$ is the quality related time (quality assurance, quality control),
– $t_{l,i}^{W}$ is the inventory holding (warehousing) time.

3.2 Scenario 2: Supply Between Two Tiers with Direct Sequencing and Shipping from Connected Lower Tier Suppliers

The second model describes the direct supply of manufacturers from suppliers, where the required number of products is higher, than the available amount of product at each individual supplier (see Fig. 2). In this case there is cooperation among the suppliers and the sequencing is made by the suppliers, so the supply problems are hidden for the manufacturers.

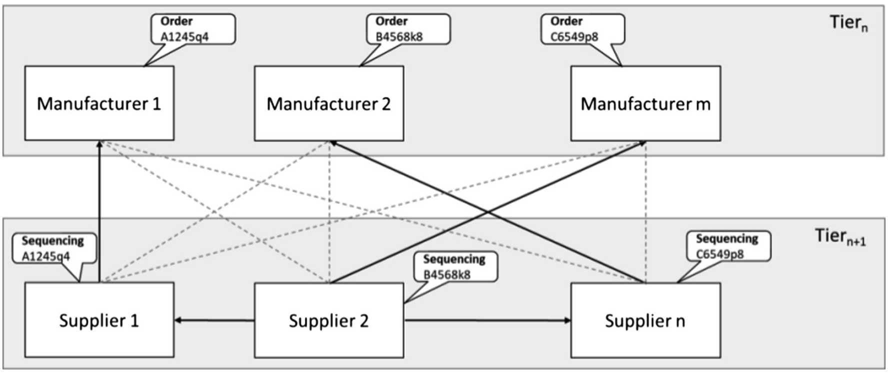

Fig. 2. Model of just-in-sequence supply between two tiers with direct sequencing and shipping from connected lower tier suppliers.

The model framework of just-in-sequence supply between two tiers with direct sequencing and shipping from lower tier suppliers has n suppliers that produce the needs for m different manufacturers.

The decision variables define the decisions to be made. In this scenario the following decisions must be made: (1) assignment of suppliers to manufacturers; (2) assignment of suppliers to sequences; (3) assignment of products produced by the suppliers to sequences of manufacturers. With this in mind, we can define the following decision variable:

- $x_{i,l,j,k}$ is the assignment matrix of manufacturers, suppliers and sequences, where $i = 1\ldots m,\ l = 1\ldots n,\ k = 1\ldots g$ and $j = 1\ldots p$.

The objective function of the problem describes the minimization of the operation costs of supply chain:

$$c_2 = \sum_{i=1}^{m} \sum_{l=1}^{n} \sum_{j=1}^{p} x_{i,l,j} \left(c_{l,f}^{CRO} + c_{l,i}^{SUP}(j) + \sum_{k \in \Theta_j} c_{l,k} \right) \rightarrow min., \quad (5)$$

where

- $c_{l,f}^{CRO}$ describes the costs of cross-transports among suppliers to fulfil manufacturers' demands where $l \neq f$.

As constraint we can define the availability of products. The availability can be taken into consideration from amount and time point of view:

$$\mathrm{q}_{i,j,k} \leq \sum_{l=1}^{n} m_{l,j,k}\ \forall k(i,j,l = const) \wedge t_{l,i,j}^{A} + t_{l,i}^{SUP} + t_{l,f}^{CRO} \leq \tau_{i,j}, \quad (6)$$

where

- $t_{l,f,k}^{CRO}$ is the required time of transportation among suppliers availability time of sequence j for manufacturer i at supplier l, which can be calculated as follows:

$$t_{l,f,k}^{CRO} = \max_{k \in \Theta_j} t_{l,f,i,j,k}^{CRO}. \quad (7)$$

3.3 Scenario 3: Supply Between Two Tiers with Indirect Supply of Manufacturers Through a Service Point

The third model (see Fig. 3) represents the indirect supply of manufacturers through a service point (3rd party logistics provider). In this case the suppliers do not communicate with each other, the products are transported directly from the suppliers to the service point, and from the service point they are delivered without sequencing to the manufacturers. The sequencing process is made by the resources of the manufacturer.

In this scenario the suppliers do not have to be assigned to the manufacturers, because the supply of them is realized through a service point. In this scenario the suppliers have to be assigned to the manufacturers as to a virtual buyer and from this point of view only the amount of different products have to be chosen to minimize the total costs and fulfil customers' demands. With this in mind, we can define the following decision variable:

- $x_{l,j,k}$ is the assignment matrix of suppliers and sequences.

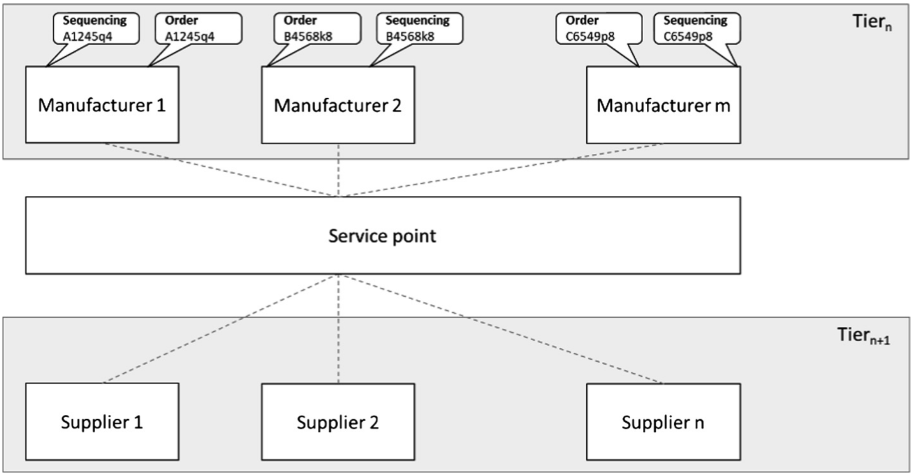

Fig. 3. Model of just-in-sequence supply between two tiers with indirect shipping through a service point from lower tier suppliers.

The objective function of the problem describes the minimization of the operation costs of supply chain:

$$c_3 = \sum_{l=1}^{n} \sum_{j=1}^{p} \sum_{k=1}^{g} x_{l,j,k} \left(c_{l,k}^{SUP}(j) + \sum_{k \in \Theta_j} c_{l,k} \right) + c_{add} \rightarrow min., \qquad (8)$$

where c_{add} is the additional supply cost among service centre and manufacturers, which is a constant cost.

As constraint we can define the availability of products. The availability can be taken into consideration from amount and time point of view as written in Eq. (2).

3.4 Scenario 4: Supply Through a Service Point from Hyperconnected Lower Tier Suppliers

The production and logistics of the suppliers are coordinated by the service point. The last model represents the most interconnected logistics systems, where the suppliers communicate with the service point (see Fig. 4). The service point coordinates the suppliers' processes and delivers sequenced products to the manufacturer.

The decision variables, the objective function and the constraints are the same as in Scenario 3. The only difference is that in this case the sequencing is also made by the service point.

This model represents a strong horizontal cooperation with vertical integration, so the application of Industry 4.0 solutions, tools and methods can be used to increase the efficiency, flexibility and availability of the interconnected supply chain:

- vertical networking of tiers to improve the information flow among tiers;
- horizontal integration of suppliers to increase the level of cooperation and enhance the flexibility, efficiency and availability of suppliers;

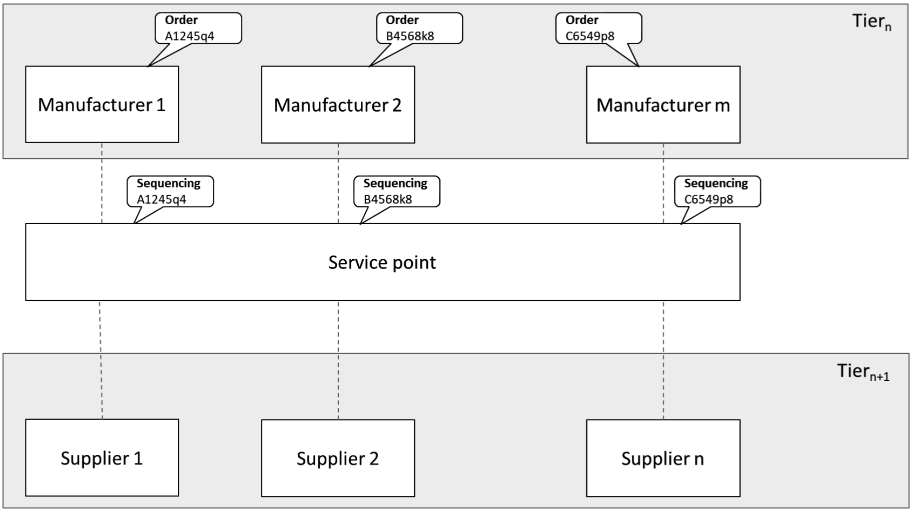

Fig. 4. Model of indirect just-in-sequence supply through a service point from hyperconnected lower tier suppliers.

– use of exponential technologies for technology, logistics IT and telecommunication.
– through engineering, these solutions are focusing on value chain and product and customer life cycles, enabling new, more flexible product processes.
– use of exponential technology solutions in corporate venturing and the learning organisation. It allows individual and flexible concept of I4.0 solutions.

As Fig. 4 shows, the horizontal integration via service point can be beneficial for internal and external processes of factories with proper IT systems. External processes can be found at partners, customers, suppliers, and even other members of ecosystems. These are basics of the RAMI 4.0, where we can use tools like life cycle analysis, value streaming calculations and early data collection for forecasting and preparation.

Stakeholders with suitable and well-connected IT systems can earn benefits such as easy information management, good costumer experiences, easy and flexible products planning and production. The most importantly we can save money, higher efficiency in the market, with workforce and better general reaction [38].

3.5 Scenario Analysis

Within the frame of this scenario analysis there are three manufacturers and three suppliers. The location of the suppliers is in Caltanissetta, Pancallo and Catania, while the suppliers are located in Canicatti, Caltagirone and Lentini. The transportation routes and required travelling times are given in Table 1.

Table 1. Distances among manufacturing plants and suppliers

Manufacturer/Supplier	Canicatti	Caltagirone	Lentini
Caltanissetta	29.4 km/40 min	89.8 km/85 min	127 km/90 min
Pancallo	106 km/122 min	123 km/126 min	118 km/106 min
Catania	134 km/112 min	67.8 km/70 min	34.3 km/36 min

There is only one sequence for each manufacturer and the matrix of required and available products can be written as follows:

$$\boldsymbol{q} = \begin{bmatrix} 255 & 200 & 100 \\ 45 & 150 & 25 \\ 100 & 200 & 300 \end{bmatrix} \boldsymbol{m} = \begin{bmatrix} 100 & 200 & 300 \\ 45 & 150 & 25 \\ 255 & 200 & 100 \end{bmatrix}. \tag{9}$$

The transportation cost for scenario 1 is calculated with Eqs. (1–4) and for scenario 2 with Eqs. (5–7). The results of the initial transportation costs are depicted in Table 2.

Table 2. Transportation costs in scenario 1 (standard transportation cost = 55 €/route, specific transportation cost = 0.014 €/km × pcs)

Manufacturer/Supplier	Canicatti	Caltagirone	Lentini
Caltanisetta	301.96	331.58	1041.79
Pancallo	945.40	433.84	971.86
Catania	1180.60	263.82	321.51

In the case of scenario 1 the total costs of the supply chain is $c_1 = 2656.23\,€$, while in the second scenario, where suppliers can fulfil manufactures demands through horizontal cooperation the total cost of the supply chain is $c_2 = 1912.81\,€$. However, in the case of the second scenario the costs of additional transportation between suppliers in Canicatti and Lentini is $c_{add} = 855.50\,€$, but the standard transportation of the available products from the nearest suppliers to the manufacturers is less, than in the first scenario, because the nearest suppliers can be taken into consideration in the supplier selection process.

Figure 5 shows the transportation routes among suppliers and manufacturers. As the solution shows, without communication and horizontal cooperation among the suppliers it is not possible to choose the nearest suppliers to minimize the transportation costs. Figure 6 shows the transportation routes in the case of scenario 2, where there is a horizontal cooperation among the suppliers to balance shortages and excesses. At the figure shows, in this scenario two suppliers are balancing their inventory. This balancing results that both suppliers can transport to the nearest manufacturer. Inventory balancing of suppliers is a core problems of Industry 4.0 based supply, therefore it is important to strengthen the horizontal cooperation.

Fig. 5. Solution of scenario 1 without horizontal cooperation of suppliers.

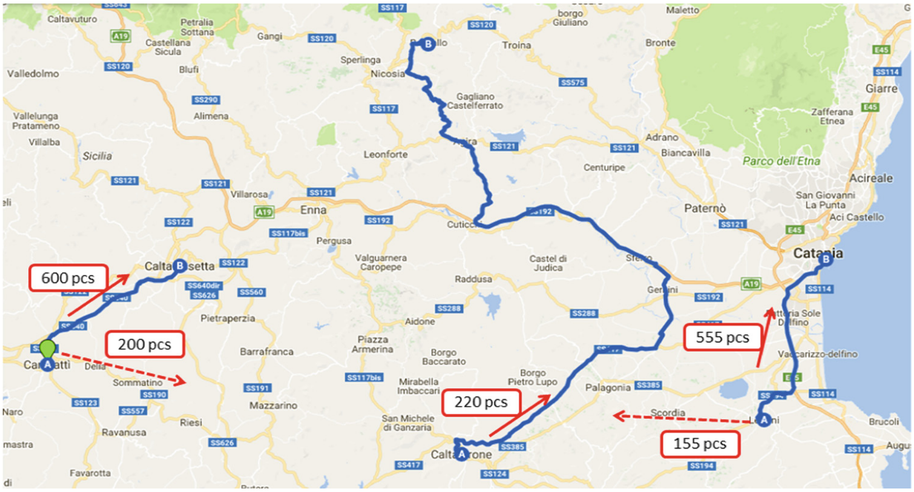

Fig. 6. Solution of scenario 2 with horizontal cooperation of suppliers in Canicatti and Lentini.

The 3rd and 4th scenarios have a centralized service point. Service points are useful if the increased transportation cost in the relations supplier – service point and service point – manufacturer is lower than the transportation among suppliers to balance inventory. The 3rd and 4th scenario has an important difference. In the 3rd scenario the sequencing is made by the suppliers and the service point is only a 3rd party logistics provider, while in the case of the 4th scenario the sequencing is made by the service point.

4 Conclusions

The Industry 4.0 solutions make it possible to develop just-in-sequence supply chain among tiers aiming economic and environmental sustainability and also for capacity use. The featured models make it possible to analyze the just-in-sequence supply chain between tiers. As the defined scenario shows, significant financial savings are available using optimized just-in-sequence solutions.

This study developed a methodological approach for modeling just-in-sequence supply. In this paper, firstly we review and systematically categorized the recent works presented for just-in-sequence supply. Then, motivated from the gaps in the literature, a model structure is developed. Four models were proposed with direct/indirect supply and sequencing, with/without horizontal cooperation.

However, there are also directions for further research. First, although the transportation routes as distances among the suppliers and manufacturers are considered in this paper, the capacities of transportation vehicles are not taken into consideration. In further studies, the model can be extended to a more complex model including capacities of vehicles and store capacities of locations. Second, this study only considered deterministic supply strategies. In reality, the requested products can be described as stochastic parameters. In complex supply chain solutions a wide range of design problems should be solved with an integrated model, where heuristic and metaheuristic solution shave to be taken into consideration. This should be also considered in the future research.

Acknowledgements. This project has received funding from the EFOP-3.6.1-16-00011 “Younger and Renewing University – Innovative Knowledge City – institutional development of the University of Miskolc aiming at intelligent specialization” project implemented in the framework of the Szechenyi 2020 program and the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691942. This research was partially carried out in the framework of the Center of Excellence of Mechatronics and Logistics at the University of Miskolc.

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