Modeling and Evaluation of Ship-to-Sequence Supply Solutions

János Juhász and Tamás Bányai

University of Miskolc, Institute of Logistics, Miskolc-Egyetemváros, HU-3515 Miskolc, Hungary; janos.juhasz1@uni-miskolc.hu; tamas.banyai@uni-miskolc.hu

Abstract: Supply chain optimization plays an important role in the cost efficiencies and sustainability for production and service companies. Novel strategies support the improvement of supply chain solutions, one of them is the just-in-sequence supply, which makes it possible to upgrade the advantages of conventional just-in-time strategies. Within the frame of this article, the authors are focusing on the evaluation of the ship-to-sequence supply, which is one of the three basic just-in-sequence supply strategies. The authors describe a novel approach to describe the optimization of ship-to-sequence supply. The numerical results validated the model and shows, ship-to-sequence supply makes it possible to improve the conventional supply strategies. The proposed approach makes it possible to analyze and evaluate the financial impact of ship-to-sequence supply, for both the supplier and end user. Not only the whole supply process, but the chosen sequencies can be also analyzed and the impact of influencing factors on the financial indicators can be evaluated.

Keywords: logistics; supply chain; reusable and non-reusable packaging; maintenance; circular economy

1 Introduction

The diversity of logistics processes requires to develop new methods and solutions for Just-in-sequence (JIS) supply chains. These developments are addressed to find the ideal corporate operation, which has become a key challenge in field of logistics today, especially in logistics processes or services areas. These activities transcend the traditional demands of the market and contrast the standard corporate operation with a performance-oriented operational management model to increase the economic and financial efficiency.

Lean, is one of the most important tools in the field of production logistics, which is related to supply chain management (SCM). The development of SCM has been identified as a key challenge for logistics, especially in the areas of manufacturing, healthcare, related logistics services, and specific industries.

The just-in-sequence supply strategy is based on the "just-in-time" philosophy, with the following differences: the goal is not only to assign the parts in the right quantity, of the right quality and in the right place, but also the focus is placed on the orders by the required technology and the right sequencing. The implementation of a just-in-sequence supply strategy can lead to even more cost savings through inventory reductions. Companies are trying to prioritize to evaluate and rate individual suppliers by the fulfillment of specific customer demands. Based on the identified challenges. We consider this research on just-in-sequence supply processes to enhance performance.

1.1 Task of Logistics and Operations

In a global approach, we can consider public services, such as transportation systems: road, railway, maritime, and air freight transportation modes [1], as sub-areas of economical and sustainable middle and long-term freight transport [2].

In an industrial approach, means an uninterrupted supply chain of complex manufacturing systems and closely related services that serve the different user demands based on optimal operation.

The challenges of responding to increasing customer demands go beyond the traditional manufacturing processes, which allow the basic products' production [3] on the same assembly line [4]. It requires to develop newer scheduling models because the planning tasks have become more complex on each manufacturing level, which requires to develop of more exact solutions [5]. We solve the scheduling sequencing problems with heuristic solutions [6].

The analysis of inventory models can be described similarly, where the core focus is to minimize operational costs [7]. The BMW manufactory is also focused on this goal [8] because it provides complex warehouse services to its customers [9].

A significant number of books and articles have been published, that describe the benefits of just-in-time and just-in-sequence, and also the application of lean systems between companies, to support the refining of exact solution methods [10].

In addition, these short case studies from the automotive industry can illustrate the practical background of just-in-sequence supply. These manufactory examples make the theoretical approach more tangible and highlight industrial relevance.

1.2 Role of Supply Chains

The analysis of integrated manufacturing systems in just-in-time and just-in-sequence supply chains can be understood by applying different methods. Furthermore, the manufacturing costs and service quality can be evaluated on the right criteria for further development, for example, the final product delivery reliability [11].

The practical application shows that auditing can significantly support to planning, designing, and eventually improving production and service processes. This allows better communication between the participants and improves the individual plant processes – in a partnership-based optimization [12]. The just-in-sequence strategy is one of the most popular lean tools because it has several well-known advantages: such as controlling costs, reducing supply chain risks [13], stabilizing ongoing inventories and their capacities through inter-organizational tiers of manufacturing supply chains, and supporting the above-mentioned external logistics service providers' tasks [14]. However, we must take into consideration developing decision-making models that define the ways to improve the quality of services to improve or restructure innovatively [15].

The just-in-time and just-in-sequence challenges define several aspects of the solutions, such as [16]:

(1) Developing the logistics problem-solving concepts

(2) Handling changeable customer demands over the whole supply chain

(3) Responding to the industrial policy change to provide the required goods and services more efficiently

(4) Restructure specific manufacturing and logistics processes

(5) Schedule efficiently of capacity utilization

(6) Increase the supply chain management (SCM)

The renewing supply chain is related to hyperconnected global supply chains require up-to-date chain strategies, which are able to support the better understanding between each other of the certain sectors. A networked partner's supply chain problem solutions depend on their mutual connections. Supply chain networks are highly effective and sustainable when partners work together and use modern technologies.

The Just-in-sequence supply include several advantages, especially in manufacturing and supplier processes. The automotive industry has been encouraged for the following tasks: to enabling the smallest lot numbers to be produced at a minimal stock level [17], focusing on the supermarkets and decentralized logistic areas [18], to minimize the overall lead time [19], improving the just-in-sequence operation of an automotive inbound logistic process [20], improving services using RFID radio frequency identification, applying artificial intelligence- [21] and cloud integration [22] to design classification models [23], as well as using trucks to deliver larger volumes and quantities of goods [24].

The manufacturing processes contain the following part of operational logistic areas: purchasing, manufacturing, customers and inverse processes.

The manufacturing and the third-party logistic (3PL) companies are connected as a multi-sequenced network, which are increasing more and more complex operational environment of the supply chain's processes, especially in manufacturing and service systems [25]. These are focusing on the just-in-sequence effects, and the smooth operation of their processes [26].

One of the most important challenges in automotive and mechatronic assembly processes is the implementation of "Industry 4.0" solutions within just-in-sequence supply chain developments [27]. The scheduling of technology and logistics resources has become a main area in the logistics market, especially for just-in-sequence supply chains. Companies are engaged to maximize supply process efficiency and reduce manufacturing and service operations costs through optimal resource allocation.

Just-in-sequence strategies are also considered as a reinterpretation of the concept of Just-in-time. These participants are integrated as a network, which can conduce to standards implementation and adopt the supply strategies like just-in-time or just-in-sequence strategies [28]. These concepts help to renew the supply chain-based manufacturing processes and to control the fulfilment of related services:

- Develop the traditional processes of supply chain
- Adapt modern and innovative methods in manufacturing and delivery processes and provide intermediate goods
- Select generation- and occupation-specific human resources [29]
- Achieve a higher service quality
- Mitigate environmental burden
- Reduce emissions of harmful substances
- Schedule and deliver the required products to serve the customers with the lowest cost through the whole supply chain
- Highlights the main characteristics of each production system network by planning and scheduling the logistical activity resources

Recent research also emphasizes that metaheuristic and hybrid optimization methods support just-in-time and just-in-sequence strategies. New approaches have addressed to solve scheduling problems such as minimizing earliness–tardiness and makespan [30], handling time windows and setup constraints [31], or applying swarm intelligence methods in restrictive scheduling environments [32]. Furthermore, hybrid algorithms combining penalty groups and idle time insertion have been proposed to enhance efficiency in flow shop and group scheduling contexts [33].

1.3 Consequences of the Literature Review

There are three typical just-in-sequence strategies, which are the following:

- Ship-to-sequence: where the necessary products are manufactured by the supplier and delivered to the users in order of sequence, even directly to the assembly line, called Strategy A.
- Pick-to-sequence: where the products not delivered by the manufacturer, the user assembles the required orders and delivers them to the user in the required sequence, called Strategy B.
- Build-to-sequence: where the user makes the necessary components for the manufacture of the products, and these are delivered to the user in order of sequence, the supplier is considered to deliver the required materials to the manufacturing of the products, depending on the complexity of the mathematical model, called Strategy C.

To achieve this goal, we consider it a key priority to develop a specific methodology for describing mathematical modelling. This research focuses on the detailed analysis of the ship-to-sequence strategies.

Section 2 presents materials and methods focusing on the mathematical model of ship-to-sequence supply solutions. Section 3 presents the numerical results of the case studies based on the mathematical model. Discussions and future research directions are discussed in the last section.

2 Materials and Methods

This chapter discusses the mathematical modeling of ship-to-sequence supply strategies to define the optimal parameters and to evaluate the optimal supply chain operation.

2.1 Define Ship-to-Sequence Parameters

Known parameters:

- $d_{ijk\tau}^{A,F}$ is the demand from i^{th} supplier to j^{th} user for k^{th} product in τ^{th} sequence,
- $d_{ijk\tau}^{A,B}$ is the quantity of product k^{th} produced by i^{th} supplier for j^{th} user in τth sequence, which is not exactly the same as the user's demand, which can increase the storage capacity and the cost of the supplier:

$$\forall\, i, j, k: \left| d_{ijk\tau}^{A,F} - d_{ijk\tau}^{A,B} \right| \tag{1}$$

- $t_{ijk\tau}^{A,F}$ is the demand date by *j^th^* user for *k^th^* product expected from *i^th^* supplier in the *τ^th^* sequence
- $t_{ijk\tau}^{A,B}$ is the manufacturing date of *k^th^* product, manufactured by *i^th^* supplier for *j^th^* user in *τ^th^* sequence, which is not the same delivery time between supplier and user:

$$\forall\, i, j, k: \left|t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B}\right| \tag{2}$$

- $c_{ijk}^{A,BM}$ is the specific production cost of *k^th^* product manufactured by *i^th^* supplier for *j^th^* user, which can also be independent of the user, but it is useful to provide a generalization of the model to take into consideration users' impact on manufacturing costs, which may be fixed for example, fixing the conditions of a contract
- $c_{ijk}^{A,BW}$ is the specific warehouse cost of *k^th^* product manufactured by *i^th^* supplier for *j^th^* user, which arises because the final product is not delivered immediately to the user
- $c_{ijk}^{A,BH}$ is the specific handling cost of *k^th^* product manufactured by ith supplier for *j^th^* user, which includes material handling costs from the final manufacturing until delivery (loading, unit load formation, and opening, commissioning, packaging, sequencing)
- $c_{ijk}^{A,BI}$ is the specific capital closure rate' cost for *k^th^* product manufactured by *i^th^* supplier for *j^th^* user
- a_{ijk}^{A} is the unit cost (per product) for *k^th^* product by *j^th^* user to *i^th^* supplier,
- $c_{i,j,\tau}^{A,S}$ is the specific delivery cost for the delivery between *i^th^* supplier and *j^th^* user for *τ^th^* sequence
- $c_{ijk}^{A,FH}$ is the specific warehouse cost at *j^th^* user of *k^th^* product manufactured by *i^th^* supplier for *j^th^* user, which includes from the received sequence to the right manufacturing position (loading, unit load formation, and opening), and also includes material handling costs from the empty post-production pallets, and the packaging waste material:

$$\forall\, i, j, k, \alpha, \beta: c_{ijk\alpha}^{A,BM} = c_{ijk\beta}^{A,BM}, c_{ijk\alpha}^{A,BW} = c_{ijk\beta}^{A,BW}, c_{ijk\alpha}^{A,BH} = c_{ijk\beta}^{A,BH}, c_{ijk\alpha}^{A,BI} = c_{ijk\tau_\beta}^{A,BI} \tag{3}$$

where the index of unit cost α and β are the number of the sequences with test time horizon. Hence, we can apply the unit cost of $c_{ijk}^{A,BM}$, $c_{ijk}^{A,BW}$, $c_{ijk}^{A,BH}$, $c_{ijk}^{A,BI}$ into the test time horizon.

These are also true for the user's costs.

This statement may also be true for the unit cost because it can be considered as a constant within a test time horizon, and therefore it is not necessary to apply $a_{ijk\tau}^{A}$.

2.2 Defining the Objective Function of a Ship-to-Sequence Strategy

The following supplier costs must be considered. The calculation is as follows:

$$C_A^B = C_A^{BM} + C_A^{BW} + C_A^{BH} + C_A^{BI} + C_A^{BS} \quad (4)$$

where C_A^{BM} is the production cost at the supplier, C_A^{BW} is the warehouse cost at the supplier, C_A^{BH} is the material handling cost at the supplier, C_A^{BI} is the capital cost at the supplier and C_A^{BS} is the shared delivery cost at the supplier.

The **production cost** for each **supplier** can be calculated as follows when the quantity produced product equals the requested quantity within the test time horizon, i.e. where:

$$\forall i: C_{Ai}^{BM} = \sum_{j=1}^{n} \sum_{k=1}^{p} \sum_{\tau=1}^{\tau_{ijk}^{max}} c_{ijk}^{A,BM} \cdot d_{ijk\tau}^{A,B} \quad (5)$$

where τ_{ijk}^{max} the maximum number of j^{th} user' demands for k^{th} product from i^{th} supplier.

The cost of production for each supplier can be calculated in the following way where the quantity manufactured is greater than the quantity required of all sequences within the test time horizon, i.e. where:

$$\forall i: C_{Ai}^{BM} = \sum_{j=1}^{n} \sum_{k=1}^{p} \sum_{\tau=1}^{\tau_{ijk}^{max}} c_{ijk}^{A,BM} \cdot d_{ijk\tau}^{A,F} \quad (6)$$

otherwise, this quantity is added to the production cost of the next time horizon.

$$\Delta C_{Ai}^{BM} = \sum_{j=1}^{n} \sum_{k=1}^{p} \sum_{\tau=1}^{\tau_{ijk}^{max}} c_{ijk}^{A,BM} \cdot \left(d_{ijk\tau}^{A,S} - d_{ijk\tau}^{A,F}\right) \quad (7)$$

Thus, the suppliers' production cost can be calculated for the test time horizon as follows, where the quantities manufactured and requested are equal:

$$C_A^{BM} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BM} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F}\right) \quad (8)$$

The suppliers' production cost can be calculated for the test time horizon as follows, where the manufactured goods exceed the requested goods, and the total production cost is charged over the test time horizon:

$$C_A^{BM} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BM} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B}\right) \quad (9)$$

The warehouse cost for each supplier can be calculated as follows when the quantity manufactured is equal to the quantity requested over the testing time horizon:

$$C_A^{BW} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BW} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B} \cdot \left(t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR}\right)\right) \quad (10)$$

where $t_{ijk\tau}^{A,TR}$ is the delivery time of k^{th} product for τ^{th} sequence from i^{th} supplier to j^{th} user. However, this ship-to-sequence calculation should meet the requirements of just-in-time principles, so the delivery of a request can be only started when has already arrived at $t_{ijk\tau}^{A,F}$ demand date, i.e. the final goods have to be stored at the supplier's warehouse in time period calculated as $\left(t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR}\right)$.

If the quantity produced and requested per order item does not match in each sequence, the warehouse cost can be calculated within the test time horizon as follows:

$$C_A^{BW} = \sum_{i=1}^{m} \left\{ \sum_{k=1}^{p} \sum_{\tau=1}^{\tau_{ijk}^{max}} \left(\tau_{seq\ A} + t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR}\right) \cdot \left[\sum_{\vartheta=1}^{\tau} \sum_{j=1}^{m} c_{ijk}^{A,BW} \cdot \left(d_{ijk\tau}^{A,B} - d_{ijk\tau}^{A,F}\right)\right] \right\} \quad (11)$$

where $\tau_{seq\ A}$ is the average cycle time between two sequences, while the value $t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR}$ is the duration after correction, which takes into account the production date of the given sequence at the supplier, the request date of the user and the duration of the delivery.

The material handling cost for each supplier can be calculated as follows when the quantity produced and requested per order item is the equal for each sequence:

$$C_A^{BH} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BH} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B} \right) \quad (12)$$

If there is a discrepancy between the quantity produced and requested per order lot, the material handling cost (since it is incurred for the sequence in question) can be determined as a function of the quantity produced:

$$C_A^{BH} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BH} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) \quad (13)$$

The capital closure rate for each supplier can be calculated as follows when the quantity produced equals the quantity demanded within the test time horizon:

$$C_A^{BI} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BI} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B} \cdot \left(t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR}\right) \right) \quad (14)$$

Similarly, for the calculation of the storage cost, since ship-to-sequence calculation should meet the requirements of just-in-time principles, so the warehouse time period can be calculated as $\left(t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR}\right)$.

If the quantity produced and required per order lot are not the equal for each sequence, the calculation of the capital closure rate within the test time horizon can be done as follows:

$$C_A^{BI} = \sum_{i=1}^{m} \left\{ \sum_{k=1}^{p} \sum_{\tau=1}^{\tau_{ijk}^{max}} \left(\tau_{seq\ A} + t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR}\right) \cdot \left[\sum_{\vartheta=1}^{\tau} \sum_{j=1}^{m} c_{ijk}^{A,BI} \cdot \left(d_{ijk\tau}^{A,B} - d_{ijk\tau}^{A,F}\right)\right] \right\} \quad (15)$$

where the time period considered for the capital closure can be calculated as $\left(\tau_{seq\ A} + t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR}\right)$, and takes into account the average cycle time between each sequence, the duration of the delivery in the supplier-customer relation, and the difference between the time of completion of the products belonging to the sequences and the time of demand.

Three main models of delivery costs can be defined, depending on the applied INCOTERMS clause.

If the delivery cost is charged to the supplier, it can be calculated for each supplier as follows:

$$\forall i: C_{Ai}^{BS} = C_{Aj}^{S} \tag{16}$$

where C_{Ai}^{S} is the total delivery cost between i^{th} supplier and all other users.

If the delivery process applies a shared cost model, the delivery cost of each supplier can be determined as follows:

$$\forall i: C_{Ai}^{BS} = \sum_{j=1}^{n} \sum_{\tau}^{\tau_{ijk}^{max}} \mu_{i,j,\tau}^{A} \cdot c_{i,j,\tau}^{A,S} \tag{17}$$

where $\mu_{i,j,\tau}^{A}$ is the constant from the interval]0;1[that defines the proportion of the total cost paid between i^{th} supplier and j^{th} user for τ^{th} sequence.

If the supply is direct, there is no other costs between the supplier and the manufacturer of the supply chain. In the present ship-to-sequence model, the supply process is fulfilled by the required sequence, which means that no other costs (other material handling, warehouse, packaging, quality control, etc.) are incurred between the supplier and the manufacturer in the supply chain. This cost is important for the types of models where:

- Sequencing occurs in an intermediate warehouse/logistics provider/cross-docking facility,
- The pick-to-sequence or build-to-sequence is prepared for supply to the manufacturer by an intermediate warehouse/logistics service provider/cross-docking facility.

At the supplier, the revenue is equal to the purchase price paid by the user, which can be defined as follows:

$$\forall i: B_{Ai}^{B} = \sum_{j=1}^{n} \sum_{k=1}^{p} \left(a_{ijk}^{A} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) \tag{18}$$

and for all suppliers can be calculated as the sum of these:

$$B_{A}^{B} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(a_{ijk}^{A} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) \tag{19}$$

The following costs should be taken into consideration for ship-to-sequence supply to the user. This cost calculation is as follows:

$$C_A^F = C_A^{FV} + C_A^{FW} + C_A^{FH} + C_A^{FS} \tag{20}$$

where C_A^{FV} is the total cost of the purchased products for all sequences in the test time horizon, C_A^{FW} is the warehouse cost at the user, C_A^{FH} is the material handling cost at the user and C_A^{FS} is the shared delivery cost at the user.

The user's **cost of purchase**, which can be paid to manufacturer can be defined as a follows:

$$\forall j: C_{Aj}^{FV} = \sum_{i=1}^{m} \sum_{k=1}^{p} \left(a_{ijk}^{A} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) \tag{21}$$

and for all users can be calculated as their sum:

$$C_A^{FV} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(a_{ijk}^{A} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B} \right) \tag{22}$$

the supplier's income is equal to the user's purchase cost, therefore can be defined in terms of (22) and (25) relations:

$$\sum_{j=1}^{n} C_{Aj}^{FV} = \sum_{i=1}^{m} B_{Ai}^{B} \tag{23}$$

The just-in-sequence supply make the **warehouse cost** for each **user** is difficult to interpret. Theoretically, there are no warehouse costs, because the required items are delivered to the assembly line (manufacturing line) in just-in-time, i.e., at the date of use. Since there is no "one piece flow" material flow at this ship-to-sequence type of just-in-sequence strategy, therefore the usage time of each sequence can be considered as the average cycle time between each sequence. This allows the warehouse costs for each user to be defined.

$$C_{Aj}^{FW} = \sum_{i=1}^{m} \sum_{k=1}^{p} \left(c_{ijk}^{A,FW} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) \tag{24}$$

then the total warehouse cost for all users:

$$C_A^{FW} = \sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{k=1}^{p} \left(c_{ijk}^{A,FW} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) \tag{25}$$

The **material handling cost** for each **user** can be calculated as follows if the quantities delivered products for each sequence exactly equal with the demands. It is a fundamental requirement for the ship-to-sequence supply of just-in-sequence strategy.

$$C_A^{FH} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,FH} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) \tag{26}$$

If the delivery cost is charged to the user, it can be calculated for each user as follows:

$$\forall j: C_{Aj}^{FS} = C_{Aj}^{S} \tag{27}$$

where C_{Aj}^{S} the total delivery cost between all other supplier and j^{th} user.

If the delivery process applies a shared cost model, the delivery cost of each user can be determined as follows:

$$\forall j: C_{Aj}^{FS} = \sum_{i=1}^{m} \sum_{\tau}^{\tau_{ijk}^{max}} \left(1 - \mu_{i,j,\tau}^{A}\right) \cdot c_{i,j,\tau}^{A,S} \tag{28}$$

Hence, the supplier and the user fully cover the delivery cost by applying well-defined shared cost model, where the following criteria must be fulfilled:

$$\sum_{i=1}^{m} C_{Ai}^{S} = \sum_{j=1}^{n} C_{Aj}^{S} \tag{29}$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{\tau}^{\tau_{ijk}^{max}} \mu_{i,j,\tau}^{A} \cdot c_{i,j,\tau}^{A,S} + \sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{\tau}^{\tau_{ijk}^{max}} \left(1 - \mu_{i,j,\tau}^{A}\right) \cdot c_{i,j,\tau}^{A,S} = C_{A}^{S} \tag{30}$$

As the result of this thought process, the evaluation function of ship-to-sequence can be defined as a cost function, which is minimalize the total cost of the supply chain participants:

$$C_A = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \sum_{\tau=1}^{\tau_{ijk}^{max}} c_{ijk}^{A,BM} \cdot d_{ijk\tau}^{A,B} + \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BW} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B} \cdot \left(t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR} \right) \right) + \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BH} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B} \right) + \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,BI} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B} \cdot \left(t_{ijk\tau}^{A,F} - t_{ijk\tau}^{A,B} - t_{ijk\tau}^{A,TR} \right) \right) + \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{\tau}^{\tau_{ijk}^{max}} \mu_{i,j,\tau}^{A} \cdot c_{i,j,\tau}^{A,S} + \sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{k=1}^{p} \left(c_{ijk}^{A,FW} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) + \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(c_{ijk}^{A,FH} \cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \right) + \sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{\tau}^{\tau_{ijk}^{max}} \left(1 - \mu_{i,j,\tau}^{A}\right) \cdot c_{i,j,\tau}^{A,S} \rightarrow min \tag{31}$$

2.3 Defining the Constraints for a Ship-to-Sequence Strategy

There are some supply system 'constraints which can be defines as type of capacity- and time constraints. The following constraints are considered in this model:

- The manufacturing capacity is available to fulfil user needs at the suppliers:

$$\forall i: CAP_{Aik} \geq \sum_{j=1}^{n} \sum_{k=1}^{p} \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F} \tag{32}$$

where CAP_{Aik} is the manufacturing capacity of *i*

- The suppliers deliver exactly the requested quantities products, which is meet with the user need:

$$\forall i,j,k,\tau: d_{ijk\tau}^{A.F} = d_{ijk\tau}^{A,B} \tag{33}$$

- The suppliers deliver each sequence at exactly the expected time, when it is requested by the user:

$$t_{ijk\tau}^{A,F} = t_{ijk\tau}^{A,B} \tag{34}$$

- The size of the sequences is defined to meet the necessary and available material handling and warehouse capacity at the users:

$$\sum_{j=1}^{n} CAP_{Aj\tau}^{H} \leq CAP_{A}^{H*} \text{ és } \sum_{j=1}^{n} CAP_{Aj\tau}^{W} \leq CAP_{A}^{W*} \tag{35}$$

where $CAP_{Aj\tau}^{H}$ is the material handling capacity of j^{th} user for τ^{th} sequence, CAP_{A}^{H*} is the available material handling capacity of the supply orders, $CAP_{Aj\tau}^{W}$ the necessary warehouse capacity of j^{th} user for τ^{th} sequence, CAP_{A}^{W*} is the available warehouse capacity of the supply orders.

- The size of the sequences is defined to meet the necessary delivery capacity at the users:

$$\sum_{j=1}^{n} CAP_{Aj\tau}^{T} \leq CAP_{A}^{T*} \tag{36}$$

where $CAP_{Aj\tau}^{T}$ is the delivery capacity of j^{th} user for τ^{th} sequence, CAP_{A}^{T*} is the available delivery capacity of the supply orders.

2.4 Decision Variables for the Ship-to-Sequence Strategy

There are different possible solutions to the ship-to-sequence strategy. In the case of direct supply, where the connection between suppliers and users is direct, the following key decision variables should be considered:

- Assigning suppliers, users and sequences to each other: this decision variable cannot concern to the user' requested products, because there is a direct supply which requires more complex supply processes for each sequence at suppliers. If there is an application of hybrid solution, for instance mix the ship-to-sequence and pick-to-sequence strategies, it is possible to consider not only the sequences but also each individual products. The decision variable can be easily integrated into the objective function and the constraints defined as the demand from i^{th} supplier by j^{th} user for k^{th} product in τ^{th} sequence will only be non-negative when there is an assignment between the supplier, user, product, and sequence concerned that will cause a supply chain to be established:

$$x_{Aijk\tau} = 0 \rightarrow d_{ijk\tau}^{A,F} = 0 \text{ otherwise } d_{ijk\tau}^{A,F} = d_{ijk\tau}^{A,F*} \tag{37}$$

- Where $x_{Aijk\tau}$ is the hypermatrix which defines the assignment between ith supplier, jth user, kth product, and τth sequence: $x_{Aijk\tau} = 1$, if there is a connection, otherwise $x_{Aijk\tau} = 0$, $d_{ijk\tau}^{A,F*}$ from i^{th} supplier to j^{th} user' pre-planning demand for product k in τ^{th} sequence.
- The size of the sequences: this decision variable has a significant effect on costs, because in the extreme case, the ship-to-sequence supply strategy can be transformed into a "one piece flow" type of supply process, which increases the delivery cost significantly, while the warehouse cost can theoretically be removed at the users, but the related material handling costs also increase

significantly. The size of sequence can be integrated into the objective function, when the upcoming demand for the full test time horizon is divided by the number of sequences, i.e.:

$$d_{ijk\tau}^{A,F} = \frac{d_{ijk\tau}^{A,FTW}}{n_{seq\ A}} \tag{38}$$

- Where $n_{seq\ A}$ is the number of sequences within the time horizon.
- The choice of delivery: the delivery cost of the supplier, if the preparation time is given for each sequence.
- Scheduling of the manufacturing at the supplier: if the supplier has a large number of product types per sequence, then a large number of product types must be manufactured in an average cycle time between two sequences, which can significantly increase manufacturing costs. However, pre-manufacturing is also possible for sequences within the test time horizon, which can reduce manufacturing costs, but it can also increase warehouse costs and capital costs significantly.

3 Results

This model has objective function components which guarantee and support the required products manufacturing and delivery in sequence: contains master data on the supplier, user, products, and sequences, as well as a comprehensive analysis of the system parameters, operational costs and service time requirements defined for the model. There are several new model variants that can be defined, so it is necessary to narrow down and select the variants for test.

Based on the above, the values of suppliers (i), users (j), products (k), and sequence (t) are defined using random functions in excel, which are allowed to range between a specified minimum and maximum value – taking into consideration the diversity of market demand and the wide product variety possible.

Table 1
Master data for define the model variants

Data	Supplier number [pcs]	User number [pcs]	Products number [pcs]	Sequences number [pcs]
Minimal number	1	1	1	1
Maximal number	3	3	10	10
Generated number	1	1	6	1

Based on Table 1. data there are three-three suppliers and users in this model. The raw material requirements for each assembly line are built up from 10 different product types, which must be delivered in 10 sequences to ensure the smooth serving of the manufacturing needs for assembly lines. Lead times are defined in days - up to a maximum of 31 days, which can be a month.

Table 2. shows that how many specific value sets of *ijkt* can be generated for each supplier, user, products and sequence, here is 900 row large pattern. We can easily check this, because the *ijkt* multiplication (3x3x10x10) also gives the total values.

Table 2

Example for the *ijkt* values generate

i	j	k	t	Values*				
Suppliers	**Users**	**Products**	**Sequences**	$d_{ijk\tau}^{A,F}$ [pcs]	$d_{ijk\tau}^{A,B}$ [pcs]	$t_{ijk\tau}^{A,F}$ [days]	$t_{ijk\tau}^{A,B}$ [days]	$t_{ijk\tau}^{A,TR}$ [days]
1	1	1	1	7	43	3	30	0.17
1	1	1	2	21	10	7	24	0.75
1	1	1	3	31	12	19	10	0.92
1	1	1	4	26	39	1	29	0.67
1	1	1	5	12	30	6	25	0.88
1	1	1	6	19	36	1	17	0.33
1	1	1	7	30	40	4	12	0.58
1	1	1	8	16	39	1	27	0.46
1	1	1	9	29	23	15	30	0.58
1	1	1	10	29	28	2	2	0.17

The supply level participants are connected to each other, and characterized by free competition to provide the transparency of the model, i.e. they are free to carry out their business activities without restriction. All suppliers can fulfill, and all users can receive the requested parts in the right sequence. Then, the *ijkt* values must be generated, this can be done in parallel by randomly generating the related system parameters together.

Table 3

Detail of the incurred costs generate

$c_{ijk}^{A,BM}$ [€/pcs]	$c_{ijk}^{A,BW}$ [€/pcs]	$c_{ijk}^{A,BH}$ [€/pcs]	$c_{ijk}^{A,BI}$ [€/pcs]	$c_{ijk}^{A,FW}$ [€/pcs]	$c_{ijk}^{A,FH}$ [€/pcs]	$c_{ij\tau}^{A,S}$ [€/pcs]	$\mu_{ij\tau}^{A}$ [%]
1.38	0.03	0.05	11.00	0.08	0.05	0.28	34.00
1.75	0.06	0.06	6.00	0.08	0.09	0.26	14.00
0.94	0.08	0.05	7.00	0.08	0.06	0.33	50.00
1.03	0.08	0.08	3.00	0.08	0.08	0.29	100.00
1.19	0.08	0.08	6.00	0.06	0.06	0.33	29.00
0.11	0.05	0.05	3.00	0.08	0.09	0.25	11.00
1.02	0.05	0.05	6.00	0.03	0.08	0.27	33.00
1.22	0.06	0.09	12.00	0.08	0.09	0.25	69.00

1.02	0.08	0.09	7.00	0.08	0.08	0.25	50.00
1.06	0.08	0.05	9.00	0.05	0.08	0.26	64.00
1.22	0.06	0.09	12.00	0.08	0.09	0.25	69.00

Also, the supplier and user costs for each *ijkt* values must be generated in parallel, as well as the shared cost rate in the supplier-user relation too (See in Table 3). Dedicated costs were considered in relation to standard pallet and vehicle layout for each deliveries.

The next step is to make the summaries according to the *SZUM t* sequence. This can be used to determine the cost value of a system element for a given sequence, i.e., represents a cost indicator to evaluate the sequences of i^{th} supplier, j^{th} user and k^{th} product.

Table 4

Detail of sum of each sequence values I

$SZUM\ t$	$d_{ijk\tau}^{A,F}$ [pcs]	$d_{ijk\tau}^{A,B}$ [pcs]	$t_{ijk\tau}^{A,F}$ [days]	$t_{ijk\tau}^{A,B}$ [€/pcs]	$t_{ijk\tau}^{A,TR}$ [days]
1 1 1	220	300	59	206	5.50
1 1 2	184	244	116	232	6.79
1 1 3	325	240	130	164	5.58
1 1 4	207	297	85	151	4.33
1 1 5	242	227	103	197	4.50
1 1 6	243	240	126	188	5.13
1 1 7	208	308	114	220	4.92
1 1 8	280	227	118	117	6.67
1 1 9	218	243	120	230	5.92
1 1 10	339	209	97	150	5.46

Table 4. summarizes the demands of j^{th} user, the quantities of manufactured k^{th} product by i^{th} supplier and the corresponding lead times in the given sequence for i^{th} supplier, j^{th} user and k^{th} product.

The costs of *ijk t* sequences can be measured and calculated in the supplier-user relation (See in Table 5), so it is exactly determined which costs are incurred by whom for the required sequences, the supply of the assembly line parts.

Table 5

Detail of sum of each sequence values II

$SZUM\ t$	K_A^{FS} [t€]	K_A^{FV} [t€]	K_A^{FW} [t€]	K_A^{FH} [t€]	K_A^{S} [t€]	a_{ijk}^{A} [t€]	B_A^{B} [t€]
1 1 1	0.06	1.32	0.02	0.01	0.08	0.00	1.32
1 1 2	0.05	1.29	0.01	0.02	0.06	0.01	1.29
1 1 3	0.04	0.41	0.03	0.02	0.08	0.00	0.41
1 1 4	0.00	1.37	0.02	0.02	0.09	0.00	1.37
1 1 5	0.05	0.45	0.02	0.02	0.07	0.00	0.45

$SZUM\ t$	K_A^{FS} [t€]	K_A^{FV} [t€]	K_A^{FW} [t€]	K_A^{FH} [t€]	K_A^{S} [t€]	a_{ijk}^{A} [t€]	B_A^{B} [t€]
1 1 6	0.05	0.12	0.02	0.02	0.06	0.00	0.12
1 1 7	0.05	1.39	0.01	0.02	0.08	0.00	1.39
…	…	…	…	…	…	…	…
3 3 6	0.02	0.81	0.01	0.01	0.09	0.00	0.81
3 3 7	0.05	0.29	0.02	0.02	0.06	0.00	0.29
3 3 8	0.02	1.40	0.01	0.01	0.06	0.01	1.40
3 3 9	0.02	0.28	0.02	0.01	0.08	0.00	0.28
3 3 10	0.05	0.24	0.01	0.01	0.06	0.00	0.24

Figure 3 shows these costs can be divided into the following cost indicator values and their percentages for each sequence.

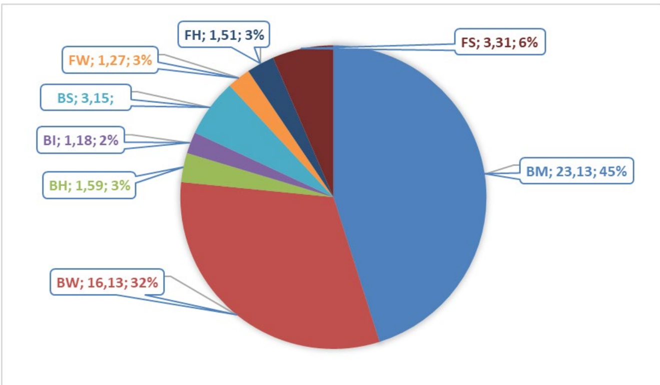

Figure 3
Results of ship-to-sequence calculations I

The above calculations can be used to determine and evaluate the costs of ship-to-sequence supply at the supplier and the user.

Based on the costs, the manufacturing-related costs are more dominant, because the customers' product requirements are concentrated there.

The logistics activity has a wide range of tasks here, which include the processing of information, the delivery of the final products, the picking processes, inventory management, the planning of the delivery processes, and other documentation service tasks.

Figure 4 represents the breakdown and its percentage of these cost indicators, where the sequence values were calculated to determine the whole operational cost of the system.

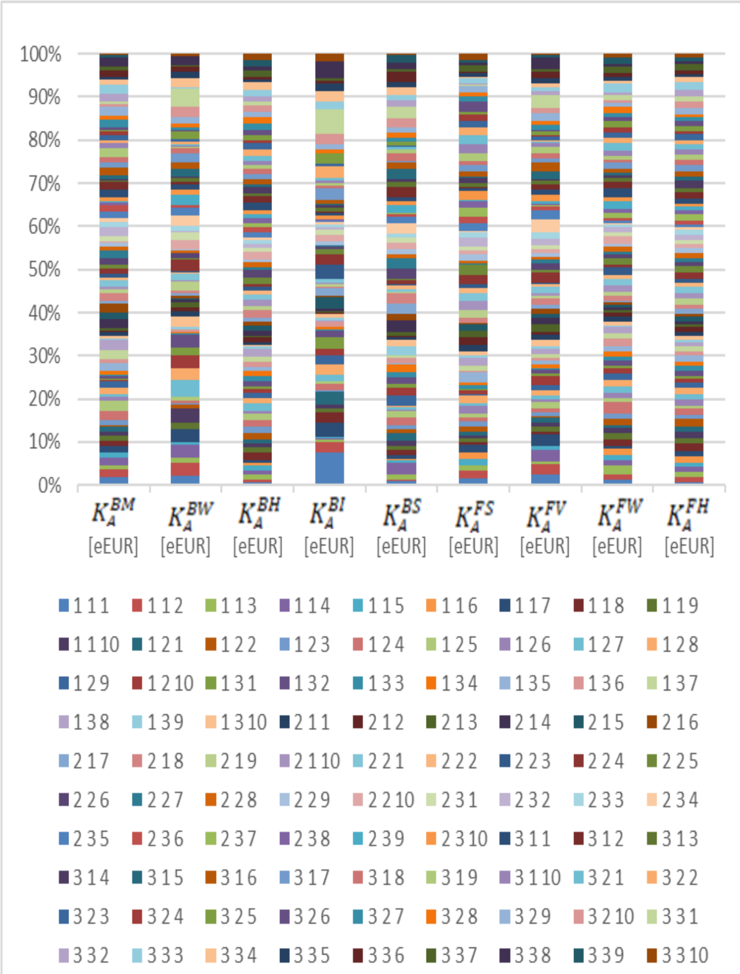

Figure 4

Results of ship-to-sequence calculations II

Based on the results of these calculation, the total cost of the ship-to-sequence supply system is 51.27 eEUR and the revenue from its activities is 53.91 eEUR. Table 6 summarizes the total costs of the whole system and also the revenue from the user.

Table 6

Summary of the ship-to-sequence calculations

C_A^{BM}	C_A^{BW}	C_A^{BH}	C_A^{BI}	C_A^{BS}	C_A^{FW}	C_A^{FH}	C_A^{FS}	$\sum C$	B_A^{B}
3.13	16.13	1.59	1.18	3.15	1.27	1.51	3.31	51.27	53.91

Conclusions

In this research, the authors investigated optimizing a company's sourcing, based on a ship-to-sequence strategy. The proposed mathematical approach makes it possible to evaluate the ship-to-sequence, from cost analysis point of view.

Hence, the results validate the usefulness of the model, which shows that the just-in-sequence supply process, is designed to enable the company to operate economically through ship-to-sequence deliveries for profit making. The application of this model enables the optimization of just-in-sequence delivery because the processes can be controlled and managed to develop heuristic optimizations.

Although the examples are illustrative, validation with real industrial data would strengthen the credibility of the model. This step could confirm the practical applicability of the approach and support its use in different industrial environments.

From a practical point of view, the presented model can be used as a decision-support tool for companies applying just-in-sequence strategies. It helps to compare different supply alternatives, identify cost-efficient supply solutions and methods, and improve the coordination between each tiers. The results also can support the implementation of more reliable and transparent sourcing processes in industrial practice.

However, there are also limitations of the study. This study took the parameters as deterministic parameters into consideration. Fuzzy modeling can also be used to analyze the impact of stochastic parameters on the efficiency of ship-to-sequence supply. Other future research direction is the analysis of the impact of logistics clusters on supply efficiency, or to discuss the potentials of electromobility in just-in-sequence supply.

The integration of Industry 4.0 solutions can also be explored to increase the flexibility and reliability of sequential processes, such as IoT-based real-time data collection, digital twins, and AI-driven forecasting.

In summary, addressing stochastic supply processes and leveraging new trends will be crucial for developing more flexible and efficient ship-to-sequence supply strategies such as electromobility, logistics clusters and Industry 4.0 solutions.

References

[1] Juhász, J., Bányai, T. Logistic aspects of real time decisions in intelligent transportation systems. In: Proceedings of the 5th International Scientific Conference on Advances in Mechanical Engineering, Hungary (12-13 October 2017)

[2] Miloslavskaya, S., Panychev, A., Myskina, A., Kurenkov, P. Intermodal transportation using inland water transport in Russia and abroad. IOP

Conference Series: Materials Science and Engineering 2021, 334, 02012 https://doi.org/10.1051/matecconf/202133402012

[3] Boysen, N., Fliedner, M., Scholl, A. Level scheduling under limited resequencing flexibility. Flexible Services and Manufacturing Journal 2010, 22(3-4), 236-257, http://www.doi.org/10.1007/s10696-010-9065-0

[4] Boysen, N., Fliedner, M., Scholl, A. The product rate variation problem and its relevance in real world mixed-model assembly lines. European Journal of Operational Research 2009, 197(2), 818-824 http://www.doi.org/10.1016/j.ejor.2008.06.038

[5] Boysen, N., Fliedner, M., Scholl, A. Level Scheduling for batched JIT supply. Flexible Services and Manufacturing Journal 2009, 21(1-2), 31-50 http://www.doi.org/10.1007/s10696-009-9058-z

[6] Boysen, N., Fliedner, M., Scholl, A. Level scheduling of mixed-model assembly lines under storage constraints. International Journal of Production Research 2009, 47(10), 2669-2684 http://www.doi.org/10.1080/00207540701725067

[7] Boysen, N., Fliedner, M., Scholl, A. Sequencing mixed-model assembly lines to minimize part inventory cost. Spectrum 2008, 30(3), 611-633 http://www.doi.org/10.1007/s00291-007-0095-2

[8] Hüttmeir, A., de Treville, S., van Ackere, A., Monnier, L., Prenninger, J. Trading off between heijunka and just-in-sequence. International Journal of Production Economics 2009, 118(2), 501-507 http://www.doi.org/110.1016/j.ijpe.2008.12.014

[9] Hillis, D. The thinking trucks. Manufacturing Engineer 2007, 86(1), 32-35 http://www.doi.org/10.1049/me:20070107

[10] Fliedner, M., Boysen, N., Scholl, A. Solving symmetric mixed-model multi-level just-in-time scheduling problems. Discrete Applied Mathematics 2010, 158(3), 222-231, http://www.doi.org/10.1016/j.dam.2009.09.013

[11] Faria, J. A., Nunes, E., Matos, M. A. Cost and quality of service analysis of production systems based on the cumulative downtime. International Journal of Production Research 2010, 48(6), 1653-1684 http://www.doi.org/10.1080/00207540802068631

[12] Hahm, J., Yano, C. A. The economic lot and delivery scheduling problem: The common cycle case. IIE Transactions 1995, 27(2), 113-125 http://www.doi.org/10.1080/07408179508936724

[13] Herrera, M. K. I. F., Portillo, M. T. E., López, R. R., Gómez, J. A. H. Lean manufacturing tools that influence an organization's productivity: Conceptual model proposed. Revista Lasallista de Investigacion 2019, 16(1), 115-133, http://www.doi.org/10.22507/rli.v16n1a6

[14] Plöger, M., Haasis, H.-D. Equitably taken just-in-sequence supply in production networks. ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb 2008, 103(9), 613-615, http://www.doi.org/10.3139/104.101334

[15] Tien, J. M., Berg, D. A calculus for services innovation. Journal of Systems Science and Systems Engineering 2007, 16(2), 129-165 http://www.doi.org/10.1007/s11518-007-5041-y

[16] Van De Pol, J. Just-in-time: On strategy annotations. Electronic Notes in Theoretical Computer Science 2001, 57, 41-63 http://www.doi.org/10.1016/S1571-0661(04)00267-1

[17] Zacharias, W. Triaton. Castrum sequence - The control center for just-in-sequence module production in the automotive supply industry. Technische Mitteilungen Krupp 2002, 8+63-66

[18] Dong, J., Zhang, L., Xiao, T. Part supply method for mixed-model assembly lines with decentralized supermarkets. Tsinghua Science and Technology 2016, 21(4), 426-434, http://www.doi.org/10.1109/TST.2016.7536720

[19] Yusriski, R., Astuti, B., Sukoyo, Samadhi, T. M. A. A., Halim, A. H. Integer Batch Scheduling Problems for a Single-Machine to Minimize Total Actual Flow Time. Procedia Manufacturing 2015, 2, 118-123 http://www.doi.org/10.1016/j.promfg.2015.07.021

[20] Kang, Y.-S., Kim, H., & Lee, Y.-H. Implementation of an RFID-Based Sequencing-Error-Proofing System for Automotive Manufacturing Logistics. Applied Sciences 2018, 8(1), 109 http://www.doi.org/10.3390/app8010109

[21] Ferencz K., Domokos J., Kovács L. Cloud Integration of Industrial IoT Systems. Architecture, Security Aspects and Sample Implementations. ACTA POLYTECHNICA HUNGARICA 21: 4 pp. 7-28, 22 p. 2024 http://www.doi.org/ 10.12700/APH.21.4.2024.4.1

[22] Shvets O., Smakanov B., Györök Gy., Kovács L. A Driver Fatigue Recognition System, Based on an Artificial Neural Network. ACTA POLYTECHNICA HUNGARICA 21: 8 pp. 211-226, 22 p. 2024 http://www.doi.org/ 10.12700/APH.21.8.2024.8.11

[23] Stauder, M., Kühl, N. AI for in-line vehicle sequence controlling: development and evaluation of an adaptive machine learning artifact to predict sequence deviations in a mixed-model production line. Flexible Services and Manufacturing Journal 2021, 34, 709-747 http://www.doi.org/10.1007/s10696-021-09430-x

[24] Čujan, Z., Fedorko, G. Supplying of Assembly Lines Using Train of Trucks. Open Engineering 2016, 6(1), 426-431, http://www.doi.org/10.1515/eng-2016-0057

[25] Goli, A., Babaee Tirkolaee, E., Soltani, M. A robust just-in-time flow shop scheduling problem with outsourcing option on subcontractors. Production and Manufacturing Research 2019, 7(1), 294-315 http://www.doi.org/10.1080/21693277.2019.1620651

[26] Cedillo-Campos, M., Morones Ruelas, D., Lizarraga-Lizarraga, G., Gonzalez-Feliu, J., & Garza-Reyes, J. Decision policy scenarios for just-in-sequence (JIS) deliveries. Journal of Industrial Engineering and Management 2017, 10(4), 581-603, http://dx.doi.org/10.3926/jiem.2090

[27] Juhász J., Bányai T. Role of Industry 4.0 in city logistics. In: Proceedings of Conference on Engineering Research in North-East Hungary, Hungary (29 May 2019)

[28] Matt, D. T., Dallasega, P., Rauch, E. Synchronization of the manufacturing process and on-site installation in ETO companies. Procedia CIRP 2014, 17, 457-462, http://www.doi.org/10.10s16/j.procir.2014.01.058

[29] Garai-Fodor M., Jäckel K. Generational and Regional Differences in Job Choice Preferences and Motivations. ACTA POLYTECHNICA HUNGARICA 21: 9 pp. 201-218, 18 p. 2024 http://www.doi.org/10.12700/APH.21.9.2024.9.14

[30] Babu, S., Girish, B. S. Neighbourhood search-based metaheuristics for the bi-objective Pareto optimization of total weighted earliness-tardiness and makespan in a JIT single machine scheduling problem. Operations Research Perspectives 2025, 14, 100335, https://doi.org/10.1016/j.orp.2025.100335

[31] de Freitas, M. G., Abreu, A. P., Branco, F. J. C., Fuchigami, H. Y., de Mello, R. T. Performance investigation of metaheuristics for the just-in-time single-machine under different time windows and setup restrictions. International Journal of Industrial Engineering Computations 2025, 16(3), 799-808 https://doi.org/10.5267/j.ijiec.2025.3.004

[32] Palominos, P. I., Mazo, M., Fuertes, G., Alfaro, M. D. An Improved Marriage in Honey-Bee Optimization Algorithm for Minimizing Earliness/Tardiness Penalties in Single-Machine Scheduling with a Restrictive Common Due Date. Mathematics 2025, 13(3), 418, https://doi.org/10.3390/math13030418

[33] Ji, Q., Han, Y., Wang, Y., Zhang, B., Gao, K. A Penalty Groups-Assisted Iterated Greedy Integrating Idle Time Insertion: Solving the Hybrid Flow Shop Group Scheduling with Delivery Time Windows. Complex System Modeling and Simulation 2024, 4(2), 137-165 https://doi.org/10.23919/CSMS.2024.0005