UNIVERSITY OF MISKOLC
FACULTY OF MECHANICAL ENGINEERING AND INFORMAICS

DEVELOPING JUST-IN-SEQUENCE SUPPLY CHAIN DESIGN METHODS

BOOKLET OF PH.D. DISSERTATION'S THESES

Prepared by

János Juhász
Technical Manager BSc
Logistics Engineer MSc
Packaging Logistics Engineer PgD

JÓZSEF HATVANY DOCTORAL SCHOOL OF INFORMATION SCIENCE
TOPIC FIELD OF MATERIAL FLOW SYSTEMS AND LOGISTICS INFORMATICS
INSTITUTE OF LOGISTICS

Head of Doctoral School
Prof. Dr. habil. Jenő Szigeti
Full Professor, DSc

Head of Topic Group
Prof. Dr. habil. Béla Illés
Full Professor

Scientific Supervisor
Prof. Dr. habil. Tamás József Bányai
Full Professor

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1. INTRODUCTION

The diversity of logistics processes requires new methods and solutions for development of just-in-sequence (JIS) supply chains. These activities are focused on the ideal company operation, which has become one of the key logistics tasks, especially in processes or services processes. These activities go beyond serving traditional market needs, as the contrast of the standard corporate operations with performance-oriented management operating model, increasing efficiency, and achieving cost-effectiveness.

Logistics must manage a wide range of logistical tasks, based on the 7M rule of getting the right product, in the right quantity, of the right quality, to the right place, at the right time, at the right cost and to the right customer. These logistics service systems include the whole supply chain, which contain the four logistics functional areas: procurement, manufacturing, distribution, and inverse processes.

In the field of production logistics, lean is one of the most important methodologies related to Supply Chain Management (SCM). The development of SCM has become a key challenge in logistics, especially in the fields of manufacturing, healthcare, and the related logistics services, and also in certain sectors. This also means that these systems must serve the rapidly changing demands of society.

Supply chain participants require up-to-date information to be able to fulfill manufacturing demands and the related logistical tasks. It requires the development of an efficient system where all participants can communicate with each other, and also serve their mutual needs. With this in mind, we are talking about a comprehensive resource management system that will help to reduce the manufacturing processes and logistics services operational costs.

Modern technologies can also be extended to more complex systems such as the automotive and mechatronic assembly industries. These systems can increase the process efficiency, reduce the resource allocation, revert the lead times, and also improve the quality.

These complex logistics and industrial solutions allow them to achieve significant changes by providing innovative and competitive possibilities to serve their customers through the integration of Industry 4.0 solutions.

Increasing efficiency can be achieved through logistics goals such as maximizing the capacity allocations, reducing the inventories, increasing the flexibility, using the Customer Relationship Management (CRM), planning the schedules, and increasing the transparency of systems and processes.

The lean philosophy is based on the Toyota Production System (TPS) principles. One of the most popular lean tools is the just-in-time (JIT) supply strategy, now also known as just-in-sequence supply strategy. 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 benefits of just-in-time supply strategies are known. The results of a survey of more than one hundred and fifty large European companies showed that the application of JIT-based supply strategies led to improvements in a number of logistics-specific system parameters: cutting the inventories in half, reducing the logistics costs, and improving the product quality of processes.

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, I consider this research on just-in-sequence supply processes to enhance performance. With dynamically changing and increasing manufacturing or service demands, an important challenge is to better understand and improve supply processes.

Before elaborating models, algorithms or solution concepts, the most important scientific results must summarize based on the literature. In next chapter, the systematic literature review is presented.

2. LITERATURE REVIEW, RESEARCH METHODOLOGY AND OBJECTIVES

Through a systematic literature search, I have examined the relevance of related research, mapped publications, and analyzed the statistical and content significance of these publications. I prepared a literature review based on a solid methodological foundation, which I carried out by developing my own methodology.

2.1. Methodology of the literature review

A Systematic Literature Review (SLR) is one of the most important scientific methods to ensure that specific research results become available for further research. These provide relevant scientific and technical information to support decision-making tasks related to design processes and help to identify conclusions for potential future research directions.

In this chapter, I presented a new methodology for systematic literature review, which has not been used before to capture or describe these guidelines [I2]. My aim is to present how the basic research can be better understand, summarized, and applied to my research. These investigations can have a significant impact on how to answer the research questions that arise, define professional guidelines, and develop specific standards.

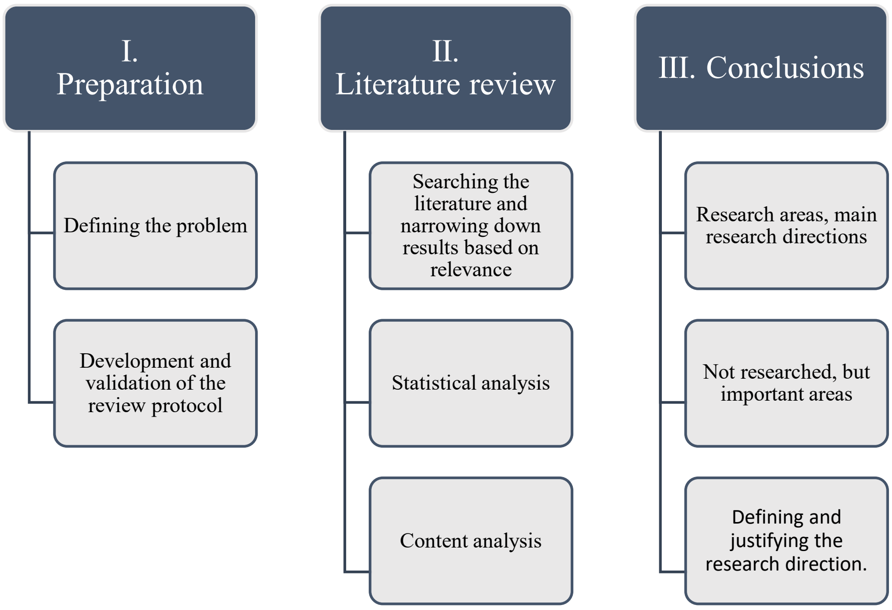

Figure 1: The methodological stages of Systematic Literary Review [Own edit]

As seen in Figure 1, the SLR process consists of three main sub-processes:

I. Preparation: identify the area to be reviewed to define the research questions and develop a review protocol;

II. Literature review: a complex review of selected publications;

III. Conclusion: capture of the findings and conclusions of the literature identified, analyzed, and reviewed, description of the analysis [I2].

I define the aspects of this new approach to methodology as follows:

- defining the problem,
- development and validation of the review protocol,
- searching the literature and narrowing down results based on relevance,
- statistical analysis,

- content analysis,
- research areas, main research directions,
- not researched, but important areas,
- defining and justifying the research direction.

In my dissertation, I have presented the detailed literature search based on the principles of the developed SLR-PDSA worksheet and the systematic literature review. Thus, the potential research directions can be identified for future development.

2.2. Conclusion, summary of main research directions

In a globalized world we can ask that question which companies able to apply the development of supply chain design and control solutions in their processes and services?
The sub-areas are defined as follows:

- logistical factors and tasks,
- JIT/JIS supply chains,
- mathematical models,
- analytical and heuristic algorithms,
- COVID-19 JIT/JIS applications.

Main directions of the research: the literature shows that there is a fierce economic competition to fulfill market needs, which can be achieved by minimizing operation costs in in-plant systems, developing (immediate) responses to customer requests, and reducing in-plant lead times.

These effects can be observed at different points in the supply chain:

I. Manufacturing and service companies are focused on being competitive in industry and markets, especially in the fields of automotive and mechatronic assembly processes,

II. These are addressed to final delivery services, including best-practice and innovative solutions to enhance the competitiveness,

III. The complexities of just-in-time based just-in-sequence systems are similar to the global supply chain systems, which are required new up-to-date supply chain methods through their diversity and complexity,

IV. The resources, as just-in-sequence supply processes based on capacity and inventory management, can be controlled according to different schedules and delivery needs,

V. The just-in-sequence strategy can support supply processes, especially in controlling logistics and service processes.

The lean philosophy is based on Toyota's Production System, which has been used as the basis for the development and implementation of new lean tools. Perhaps, the most popular lean tool is the just-in-time supply strategy and the more recent just-in-sequence supply strategies which are developed on this basis.

The logistics functional areas already mentioned should be monitored to ensure that the individual manufacturing and service processes ensure an economical flow of the final product throughout the supply chain.

2.3. Research objectives

Based on the systematic literature search conducted in the subsections and the relevance of the topic of this Ph.D. dissertation, the objectives of this research can be summarized as follows:

- designing a model system to analyze the in-plant just-in-sequence processes and deriving some typical supply model variant from the model system,
- developing a suitable modeling system to analyze just-in-sequence processes in-plant and deriving the characteristic supply models from the developed model system,
- summarizing the future development possibilities.

The optimal design of logistics processes has become a key task in a globalized economy on the threshold of the current recession, as the participants in the business segment can reduce their costs essentially by optimizing their logistics systems.

Supply chain modeling has an important impact on this discipline, the logistical background to supply chain modeling will be discussed in further sections. According to my objectives, it can be shown that in-plant processes can be developed in order to create a decision-support system structure that contributes to more sustainable corporate operations.

3. THE MODEL STRUCTURE OF JUST-IN-SEQUENCE SUPPLY SYSTEMS

In this chapter I describe the supply chain characteristics of just-in-sequence (JIS) supply chains and develop a decision support system structure. In this chapter of my dissertation, the necessary elements for the modeling and the system structure are described in further detail after a topic delimitation.

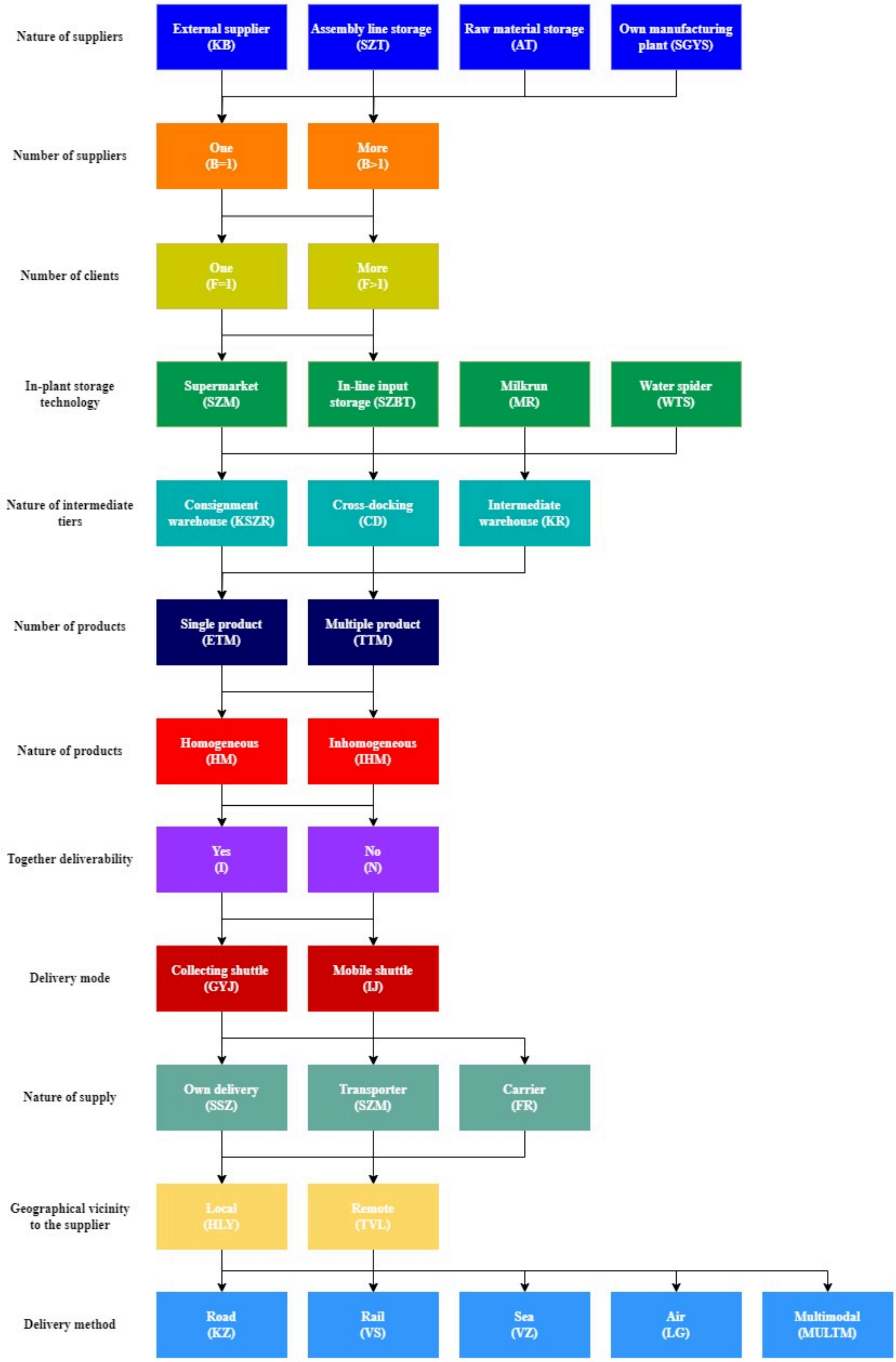

Figure 2: The new model structure of just-in-sequence supply systems [Own edit]

As Figure 2 shows, the raw material supply requirements of manufacturing processes are quite variable, so the required components for production depend on the component assembly demanded. The delivered products provide the raw materials for the manufacturing process because these materials are used to produce the required final product. According to different logistical needs, it is delivered to the assembly line, where directly assembled. Figure 2 shows the 46080 pieces options.

The system structure contains the necessary aspects that determine the supplier material flow in the supply chain. The continuously changing customers' needs are required to identify unexpected situations, respond promptly, and meet customer expectations.

Supply chains have a number of challenges which need to be solve and elaborate models taking into consideration logistical factors. In practice, it provides a comprehensive set of criteria that supports the making of strategic decisions, thus allowing the selection of the optimal supply strategy.

An ideal supply relation can have several advantages, which include:

a) supplier control costs can be minimized,
b) low inventory costs can be obtained by application of optimal procurement strategy,
c) quality risks can be reduced.

The double objective can be defined on the customer and manufacturer side: to serve the diverse customer needs that arise on the customer side, and to keep processes and services organized and efficient on the business side.

4. MATHEMATICAL DESXRIPTION OF JUST-IN-SEQUENCE SUPLLY SYSTEMS

In this chapter, the system structure is used to derive the system variables, which can be clearly specified using the mathematical tools (mathematical modelling). The fourth chapter discusses the model elements of mathematical modeling and optimization.

Mathematical models enable us to analyze and evaluate the performance of the logistics system to support manufacturing, purchasing, distribution, and inverse processes, as well as to improve the efficiency of other service activities.

The system parameters can be selected and fine-tuned to ensure coherent and economical operation of the system. Material flow systems are characterized with wide range of size and diversity parameters.

In a material flow system and in its subsystems, the material flow and the material flow volume can be described in matrix form [I78].

The following vector describes the groups of components in the relation matrix as defined in the dissertation, and the x^{th} element number, hence the number of elements:

$$\boldsymbol{V^{\psi}} = \left| \begin{matrix} BSZ & RT & FR & GY \\ x_{BSZ} & x_{RT} & x_{FR} & x_{GY} \end{matrix} \right|, \text{ where} \quad (1)$$

- ψ is the number of different possible system elements,
- x_{BSZ} is the x^{th} element number of the suppliers,
- x_{RT} is the x^{th} element number of the warehouses,
- x_{FR} is the x^{th} element number of the carriers,
- x_{GY} is the x^{th} element number of the manufacturer assembly lines.

$$\boldsymbol{V^{\psi}} = \{1,1,1,1\}, \text{ where} \quad (2)$$

- if any element of $\boldsymbol{V^{\psi}}$ is 1, then $x = 1$ a given system element is exactly one,
- if any element of $\boldsymbol{V^{\psi}}$ is greater than 1, then $x > 1$ there are multiple system elements,
- if any element of $\boldsymbol{V^{\psi}}$ is 0, then $x = 0$ a given system element is not available, it cannot be defined.

Two different systems can be defined, based on the (2) $\boldsymbol{V^{\psi}}$ vector:

I. The single sub-system is formed by the elements of the structure in a row layout (see Figure 3),
II. The multiple sub-system, the parallel layout (see Figure 4).

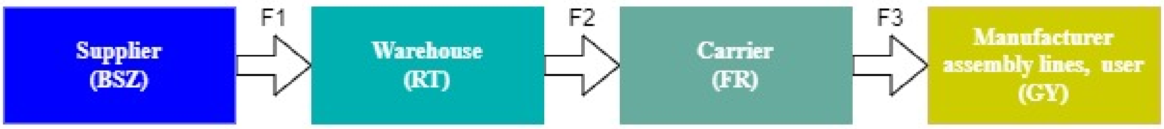

Figure 3: An example of a single sub-system [Own edit]

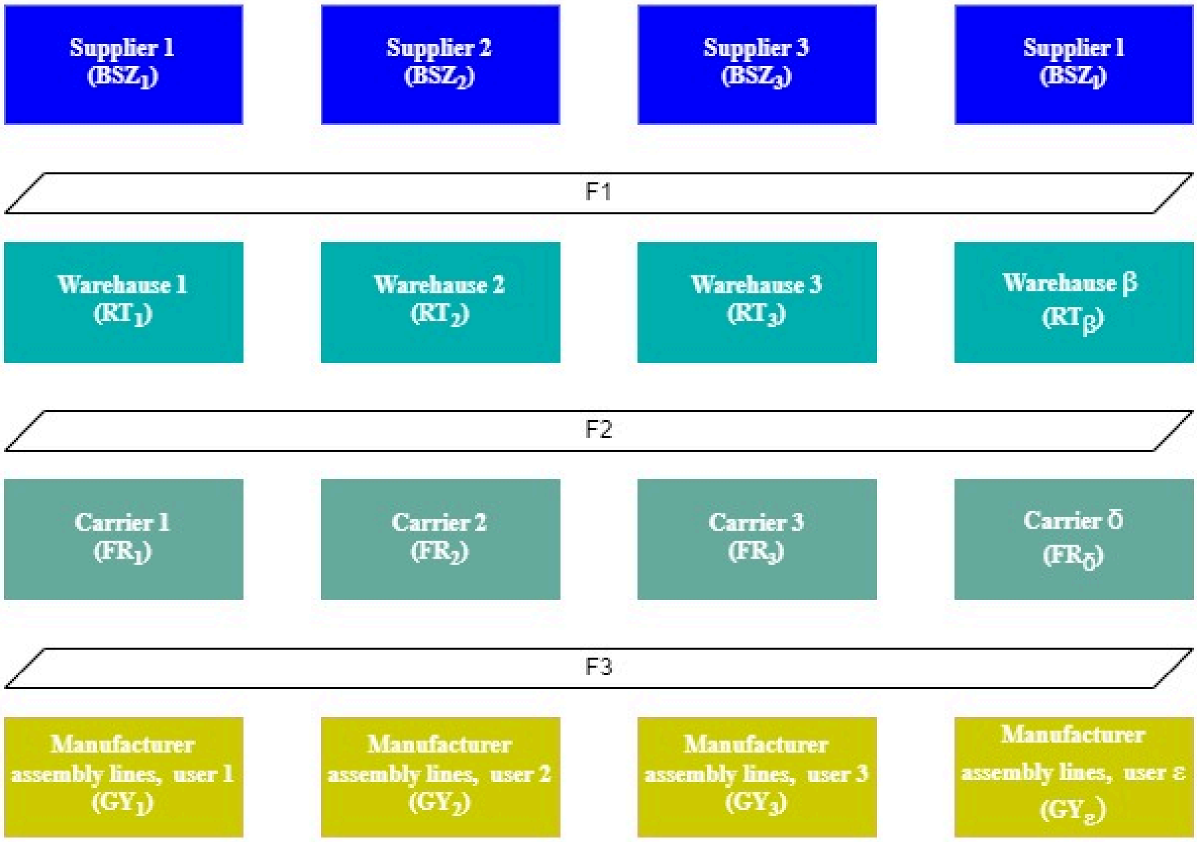

Figure 4: An example of a multiple sub-system [Own edit]

My aim is to examine some typical basis models and sub-systems by using different methods to compare the presented just-in-sequence supply system parameters for future developments.

The novelty of this research is that complex and diverse company needs are requiring the formulation of new and innovative system solutions that can lead to significant economic efficiency in the development of companies' manufacturing and service processes.

I developed a new model structure of just-in-sequence supply systems, from which can be derived some typical system variation for further testing.

The systematic structure is considered to define the mathematical model background of the just-in-sequence supply system, which describes the parameters of the system and its individual system elements. For suppliers, warehouses, carriers, and manufacturers, I have described the system parameters, objective functions, and constraints that must be considered when developing specific model scenarios.

5. MATHEMATICAL MODELLING OF JUST-IN-SEQUENCE SUPLLY STRATEGIES

The chapter discusses the mathematical modeling of just-in-sequence supply strategies that define the operational sustainability of companies' in-plant just-in-sequence supply chain processes, especially in cost and sequence. Furthermore, system variations will be numerically analyzed, evaluated, and compared.

The aim is to model the three strategies, and then compare and analyze the models' effectiveness, which can be used to select the right just-in-sequence strategy.

Just-in-sequence supply enables manufacturing operations to be designed consistently, using a combination of efficient methods [I67], because it places the company's manufacturing processes on modern and economical supply strategies [I79]. One important difference is that just-in-sequence supply enables multiple tiers of supply [S6]. It requires a unique design and a product type-specific approach to supply that serves customer demands from the beginning [I80].

To achieve the above goal, I consider it a key priority to develop a similar methodology for describing mathematical modelling for all three strategies. In the mathematical modelling, I have defined the known parameters (system characteristics), objective functions, constraints, and decision variables, which are typically time- and capacity-based.

This section provides a summary of the main characteristics, related objective functions and decision variables of the JIS supply strategies. The modelling can be found in the corresponding chapter of this dissertation.

5.1. Modelling of the ship-to-sequence

The ship-to-sequence is where the necessary products are manufactured by the supplier and delivered to the users in order of sequence.

In a ship-to-sequence supply strategy, large inventories of users are not stocked, typically in a pull system, but it's moved to the earlier points in the supply chain. In this way the supply strategy is more consistent with the just-in-sequence principles.

Thus, the sequenced order of k^{th} product does not take place at the user, but at the supplier, either in an intermediate warehouse or in a cross-docking facility.

The result of the above ideas is that a cost function for evaluating the ship-to-sequence supply strategy can be defined as a cost function that seeks to minimize the overall cost of the supply chain participants:

$$K_A = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\sum_{\tau=1}^{\tau_{ijk}^{max}} c_{ijk}^{A,BM}\cdot d_{ijk\tau}^{A,B} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{A,BW}\cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B}\cdot\left(t_{ijk\tau}^{A,F}-t_{ijk\tau}^{A,B}-t_{ijk\tau}^{A,TR}\right)\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{A,BH}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B}\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{A,BI}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,B}\cdot\left(t_{ijk\tau}^{A,F}-t_{ijk\tau}^{A,B}-t_{ijk\tau}^{A,TR}\right)\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{\tau}^{\tau_{ijk}^{max}} \mu_{i,j,\tau}^{A}\cdot c_{i,j,\tau}^{A,S} + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{p}\left(c_{ijk}^{A,FW}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F}\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{A,FH}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{A,F}\right) + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{\tau}^{\tau_{ijk}^{max}}\left(1-\mu_{i,j,\tau}^{A}\right)\cdot c_{i,j,\tau}^{A,S} \rightarrow min \quad (3)$$

where:

- $d_{ijk\tau}^{A,F}$ 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 τ^{th} sequence,
- $t_{ijk\tau}^{A,F}$ 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,
- $t_{ijk\tau}^{A,TR}$ is the delivery time from i^{th} supplier to the j^{th} user for the τ^{th} sequence request for k^{th} product,
- $c_{ijk}^{A,BM}$ is the specific production cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{A,BW}$ is the specific warehouse cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{A,BH}$ is the specific handling cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{A,BI}$ is the specific capital closure rate' cost for k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{i,j,\tau}^{A,S}$ is the specific delivery cost for the delivery between i^{th} supplier and j^{th} user for τ^{th} sequence,
- $c_{ijk}^{A,FW}$ is the specific warehouse cost at j^{th} user of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{A,FH}$ is the specific handling cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $\mu_{i,j,\tau}^{A}$ is the constant of the shared cost model.

In the case of direct supply, where the connection between suppliers and users is direct, the following key decision variables should be considered:
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:

$$x_{Aijk\tau} = 0 \rightarrow d_{ijk\tau}^{A,F} = 0 \text{ otherwise } d_{ijk\tau}^{A,F} = d_{ijk\tau}^{A,F*}, \quad (4)$$

where: $x_{Aijk\tau}$ hypermatrix which defines the assignment between i^{th} supplier, j^{th} user, k^{th} product k, and 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.

5.2. Modelling of pick-to-sequence

The pick-to-sequence is where the user assembles the required orders and delivers them to the user in the required sequence.

The pick-to-sequence supply strategy can only be considered as just-in-sequence if the procurement process of the inventory for the supply of the assembly lines is considered. For this reason, the pick-to-sequence strategy is applied again well in the supplier-user relation, because each supplier has the necessary competencies to enable just-in-time supply, and the principle of just-in-sequence is only applied within the user's facilities.

Thus, the product is not delivered to the user's facilities in the order in which it is required, namely the incoming components may be in the assembly line or the JIS raw material storage at the manufacturing site. In this case, the required sequences by the user are assembled before the assembly lines or at an earlier point in the supply chain, such as an intermediate warehouse or a cross-docking facility.

The result of the above ideas is that a cost function for evaluating the pick-to-sequence supply strategy again can be defined as a cost function that seeks to minimize the overall cost of the supply chain participants:

$$K_B = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\sum_{\tau=1}^{\tau_{ijk}^{max}} c_{ijk}^{B,BM}\cdot d_{ijk\tau}^{B,B} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{B,BW}\cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{B,B}\cdot\left(t_{ijk\tau}^{B,F}-t_{ijk\tau}^{B,B}-t_{ijk\tau}^{B,TR}\right)\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{B,BH}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{B,B}\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{B,BI}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{B,B}\cdot\left(t_{ijk\tau}^{B,F}-t_{ijk\tau}^{B,B}-t_{ijk\tau}^{B,TR}\right)\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{\tau}^{\tau_{ijk}^{max}} \mu_{i,j,\tau}^{B}\cdot c_{i,j,\tau}^{B,S} + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{p}\left(c_{ijk}^{B,FW}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{B,F}\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{B,FH}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{B,F}\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{B,FE}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{B,F}\right) + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{\tau}^{\tau_{ijk}^{max}}\left(1-\mu_{i,j,\tau}^{B}\right)\cdot c_{i,j,\tau}^{B,S} \rightarrow min \quad (5)$$

where:

- $d_{ijk\tau}^{B,F}$ is the demand from i^{th} supplier to j^{th} user for k^{th} product in τ^{th} sequence,
- $d_{ijk\tau}^{B,B}$ is the quantity of product k^{th} produced by i^{th} supplier for j^{th} user in τ^{th} sequence,
- $t_{ijk\tau}^{B,F}$ is the demand date by j^{th} user for k^{th} product expected from i^{th} supplier in the τ^{th} sequence,
- $t_{ijk\tau}^{B,B}$ is the manufacturing date of k^{th} product, manufactured by i^{th} supplier for j^{th} user in τ^{th} sequence,
- $t_{ijk\tau}^{B,TR}$ is the delivery time from i^{th} supplier to the j^{th} user for the τ^{th} sequence request for k^{th} product,
- $c_{ijk}^{B,BM}$ is the specific production cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{B,BW}$ is the specific warehouse cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{B,BH}$ is the specific handling cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{B,BI}$ is the specific capital closure rate' cost for k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{i,j,\tau}^{B,S}$ is the specific delivery cost for the delivery between i^{th} supplier and j^{th} user for τ^{th} sequence,
- $c_{ijk}^{B,FW}$ is the specific warehouse cost at j^{th} user of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{B,FH}$ is the specific handling cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{B,FE}$ is the other specific cost of sequences of k^{th} products manufactured by i^{th} supplier for j^{th} user,
- $\mu_{i,j,\tau}^{B}$ is the constant of the shared cost model.

There are also several solutions for the pick-to-sequence strategy too. Similarly, In the case of direct supply, where the connection between suppliers and users is direct, the following key decision variables should be considered:
The decision variable can be easily integrated into the objective function and the constraints defined (Eq. 4) 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:

$$x_{Bijk\tau} = 0 \rightarrow d_{ijk\tau}^{B,F} = 0 \text{ otherwise } d_{ijk\tau}^{B,F} = d_{ijk\tau}^{B,F*}, \quad (6)$$

where: $x_{Bijk\tau}$ is similarly hypermatrix which defines the assignment between i^{th} supplier, j^{th} user, k^{th} product k, and sequence: $x_{Bijk\tau} = 1$, if there is a connection, otherwise $x_{Bijk\tau} = 0$, $d_{ijk\tau}^{B,F*}$ from i^{th} supplier to j^{th} user' pre-planning demand for product k in τ^{th} sequence.

5.3. Modelling of build-to-sequence

The build-to-sequence is 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 build-to-sequence supply strategy can be considered to be most just in sequence because the components for commissioning are manufactured at the user's site according to the order and the sequence needs.

Thus, the product is delivered to the user's facilities, such as the JIS material warehouse on the assembly line or on the production site, in the order required.
Sometimes not all components can be manufactured locally, in this situation parts are also made according to the user's needs but may be completed with additional components in an intermediate warehouse or cross-docking facility.

The result of the above ideas is that a cost function for evaluating the build-to-sequence supply strategy also can be defined as a cost function that seeks to minimize the overall cost of the supply chain participants:

$$K_C = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\sum_{\tau=1}^{\tau_{ijk}^{max}} c_{ijk}^{C,BM}\cdot d_{ijk\tau}^{C,B} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{C,BW}\cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{C,B}\cdot\left(t_{ijk\tau}^{C,F} - t_{ijk\tau}^{C,B} - t_{ijk\tau}^{C,TR}\right)\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{C,BH}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{C,B}\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{C,BI}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{C,B}\cdot\left(t_{ijk\tau}^{C,F} - t_{ijk\tau}^{C,B} - t_{ijk\tau}^{C,B}\right)\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{\tau}^{\tau_{ijk}^{max}} \mu_{i,j,\tau}^{C}\cdot c_{i,j,\tau}^{C,S} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{C,FM}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{C,F}\right) + + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{p}\left(c_{ijk}^{C,FW}\cdot\sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{C,F}\right) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\left(c_{ijk}^{C,FH}\cdot \sum_{\tau=1}^{\tau_{ijk}^{max}} d_{ijk\tau}^{C,F}\right) + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{\tau}^{\tau_{ijk}^{max}}\left(1-\mu_{i,j,\tau}^{C}\right)\cdot c_{i,j,\tau}^{C,S} \rightarrow min \quad (7)$$

where:

- $d_{ijk\tau}^{C,F}$ is the demand from i^{th} supplier to j^{th} user for k^{th} product in τ^{th} sequence,
- $d_{ijk\tau}^{C,B}$ is the quantity of product k^{th} produced by i^{th} supplier for j^{th} user in τ^{th} sequence,
- $t_{ijk\tau}^{C,F}$ is the demand date by j^{th} user for k^{th} product expected from i^{th} supplier in the τ^{th} sequence,
- $t_{ijk\tau}^{C,B}$ is the manufacturing date of k^{th} product, manufactured by i^{th} supplier for j^{th} user in τ^{th} sequence,

- $t_{ijk\tau}^{C,TR}$ is the delivery time from i^{th} supplier to the j^{th} user for the τ^{th} sequence request for k^{th} product,
- $c_{ijk}^{C,BM}$ is the specific production cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{C,BW}$ is the specific warehouse cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{C,BH}$ is the specific handling cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{C,BI}$ is the specific capital closure rate' cost for k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{C,FM}$ is the specific production cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{C,FW}$ is the specific warehouse cost at j^{th} user of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{ijk}^{C,FH}$ is the specific handling cost of k^{th} product manufactured by i^{th} supplier for j^{th} user,
- $c_{i,j,\tau}^{C,S}$ is the specific delivery cost for the delivery between i^{th} supplier and j^{th} user for τ^{th} sequence,
- $\mu_{i,j,\tau}^{C}$ is the constant of the shared cost model.

There are also several solutions for the build-to-sequence strategy too. In this third model there is direct supply, where the connection between suppliers and users is direct, the following key decision variables should be considered:
The decision variable can be easily integrated into the objective function and the constraints also defined (Eq. 4) and (Eq. 6) 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:

$$x_{Cijk\tau} = 0 \rightarrow d_{ijk\tau}^{C,F} = 0 \text{ egyébként } d_{ijk\tau}^{C,F} = d_{ijk\tau}^{C,F*}, \quad (8)$$

where: $x_{Cijk\tau}$ also hypermatrix which defines the assignment between i^{th} supplier, j^{th} user, k^{th} product k, and sequence: $x_{Cijk\tau} = 1$, if there is a connection, otherwise $x_{Cijk\tau} = 0$, $d_{ijk\tau}^{C,F*}$ from i^{th} supplier to j^{th} user' pre-planning demand for product k in τ^{th} sequence.

5.4. Mathematical modelling of complex just-in-sequence supply systems

The result of deriving the typical models is that I can apply the already developed and mathematically described system parameters, depending on which strategies are combined. In this sub-chapter, I have designed a specific mixed (build-to-sequence and ship-to-sequence) model, what I have described in this dissertation.

The success of just-in-sequence supply is based on the achievement of a continuous, smooth, and consistent flow of materials through the manufacturing assembly lines, namely the correct sequencing of orders for manufacturing, such as necessary components and auxiliary materials.

In contrast to traditional just-in-time supply, this will be avoided:

- the unnecessary inventory of parts,
- and waste of resources or material due to supply chain process disruptions,
- and allocation mistakes.

5.5. Numerical analyses and comparisons of typical just-in-sequence models

Mathematical modelling of just-in-sequence supply strategies has enabled optimal system parameters for all three basic supply strategies in deterministic and stochastic environments.

The numerical analysis, which is essentially a virtual case study based on the proposed models, demonstrates the applicability and understandability of the model.

COMPARING THE RESULTS OF INCOME CALCULATIONS [eEUR]				
Supply strategy	**Cost**	**Income**	**Savings**	**%**
Ship to sequence	51,27	53,91	2,64	5%
Pick to sequence	50,06	50,49	0,43	1%
Build to sequence	45,22	74,46	29,24	65%

Table 1: Results of income calculations [Own edit]

Table 1 describes the income of the supply strategy, as the choice of each supply strategy determines the savings that could be achieved by fulfilling the requested products at the assembly line.

The results of the analyses can be used to determine which just-in-sequence supply strategy is more efficient and cost-effective for the supply chain. In this case, build-to-sequence supply showed a 65% profit rate.

The application and optimization potential of just-in-sequence supply chains could be investigated in hybrid models, especially in the decision-making processes of automotive and mechatronics companies.

6. THE APPLICATION AND OPTIMISATION OF JUST-IN-SEQUENCE SUPPLY CHAINS

The objective of this chapter is to development of a decision support model to measure the efficiency of supply chains' inventory management activities, especially in manufacturing processes.

Inventory management is responsible for ensuring the required materials for manufacturing processes and services. The fictive company's sets of products were analyzed to determine that which products are economically significant. The results can be able to improve decision making and evaluate the inventory strategies. The just-in-sequence strategy support the supply processes to control their logistic processes and services.

The acceptance of inventory management in just-in-sequence solutions appears to be intensive in manufacturing technology. Just-in-sequence supply processes based on efficiency of the stocks lead to control the material flows within different scheduling and delivering needs, while the operation costs can be significantly reduced.

However, the optimal purchasing portfolio is led to increased usage of supply chain:

- the minimalization of the level of stocks and materials,
- increasing efficiency of inventory management activities,
- solving decision making problems,
- improving material flow intensity and
- evaluating in aspects of natural and costbased objective functions.

The ABC analysis is one of the most important tools to optimize inventory, where the volumes are taken into consideration. The ABC analysis has a good performance in the case of low uncertainties.

In the case of measurable uncertainties of sales, the rate of uncertainties must be taken into consideration. This aspect adds a new dimension to the ABC analysis and this method is the ABC-XYZ analysis, which focuses on both volumes and their uncertainties (see Figure 5).

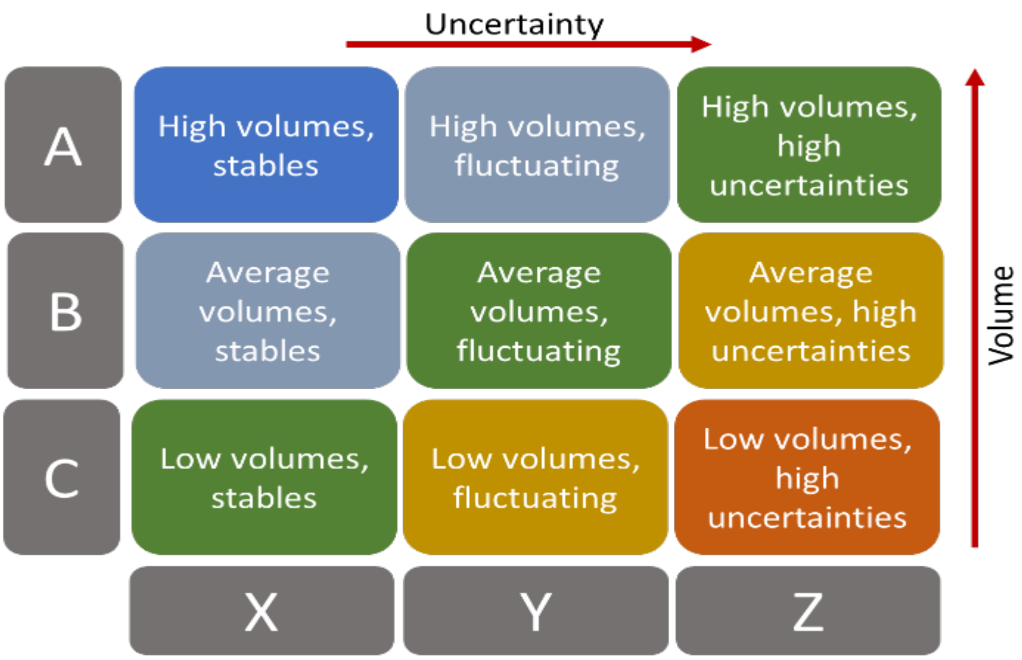

Figure 5: The structure of an ABC-XYZ matrix [Own edit]

The efficiency of stocks can be examined by mathematical and heuristic methods. To evaluate and compare traditional, consignment, JIT, and JIS supply strategies, I define the following costs:

- production costs,
- storage costs,
- ordering costs,
- shipping costs,
- inverse costs, and
- natural costs.

The objective functions of the problems describe the minimization of the inventory costs of supply chain (eq. 76): manufacturing, warehousing, ordering, delivery, replacement, and natural costs:

$$C = \sum C_{man} + C_{ware} + C_{ord} + C_{del} + C_{repl} + C_{nat} \rightarrow min, \text{ where} \tag{9}$$

- C_{man} are the manufacturing costs [EUR],
- C_{ware} are the warehousing costs [EUR],
- C_{ord} are the ordering costs [EUR],
- C_{del} are the delivery costs [EUR],
- C_{repl} are the replacement costs [EUR],
- C_{nat} is the cost of natural resources [EUR].

The application of the ABC-XYZ classification defines the products of different importance. Table 2. represents our matrix model approach to classify the inventory strategies (JIS, JIT, consignment, traditional) along the product activities and variables into nine different classes (AX, …, CZ).

ABC-XYZ Classification	**A**	**B**	**C**
X	JIS		Traditional
Y	JIT		
Z	Consignment		

Table 2: ABC-XYZ classification model for supply strategies [Own edit]

The ABC analysis can be used for several levels, where the selected inventory products are categorized into groups according to relative frequency of value and each group develop differentiated inventory management systems. In the XYZ analysis (see Figure 5.), products can be classified based on usage fluctuations and forecast accuracy.

Based on the values of annual cost of usage in Figure 6., we can see that the largest percentage of our products (45%) are covered by just-in-sequence strategy.

As a summary for the above-described ABC-XYZ analysis we can say, that based on the results of the combined ABC and XYZ analysis shown the optimal purchasing method can be chosen depending on the volume of products and the uncertainties of data. The assignment of purchasing strategies (JIS, JIT, Consignment, Traditional) depends on the size of each cluster in the ABC-XYZ matrix and the cost efficiency of purchasing strategies. For example, in the case of „AX" product cluster the just-in-sequence supply is the optimal solutions, while in the case of „XC" product cluster the traditional supply or the supply through a consignment store is the most suitable purchasing method.

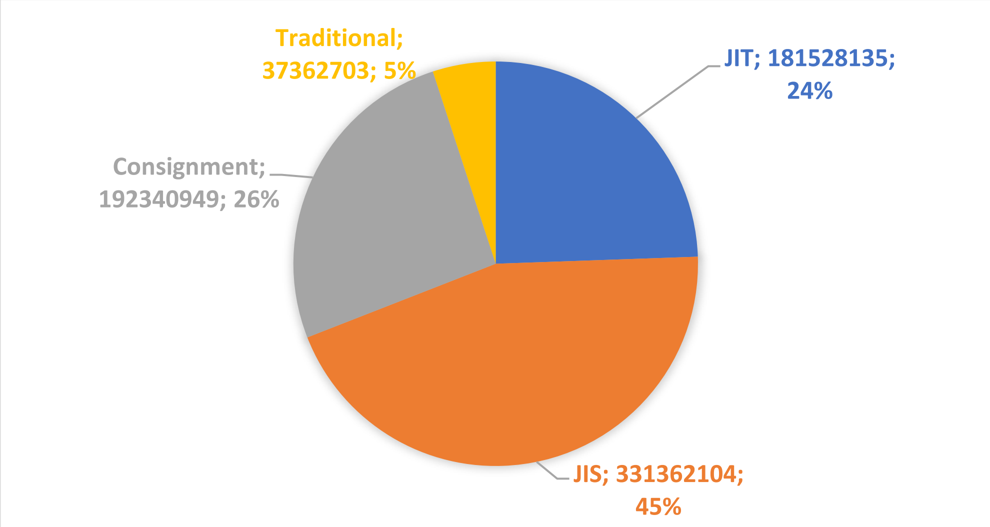

Figure 6: Procurement costs for each stocking strategy (sorted by in strategy and unit costs) [Own edit]

Figure 6. demonstrates the results of the ABC-XYZ classification classes of percentage. The most costs of product are related to JIS supply strategy, where the material flow is high and permanent use. Also, we can identify that products which are needed more or less attention.

The above-mentioned analysis method is limited, because in the case of unknow or dynamic uncertainties, the product clusters are permanently changing, therefore it is not possible to choose the best purchasing method for a longer time window.

Nonetheless, there are also further directions in research. Formulation of other optimization models and solution methods can be extended with stochastic environment to solving multiple scheduling problems.

7. SUMMARY

The choice of the topic for the Ph.D. dissertation was inspired by the companies' experiences and the increasingly difficult economic situation. The manufacturing and service companies are in a difficult situation, because they have newer and newer tasks to solve as a daily challenge. The scope of these activities focuses on companies' production processes and logistics services – from the procurement of the necessary raw materials to the recycling of used products.

The corporate decisions are targeted to create a smooth and economical operating environment, as well as to design, implement and operate their optimal logistics material flow processes by the application of supply chain solutions.

I would like to highlight the importance of the Hungarian Industrial Development Strategy, because the manufacturing changes are fundamentally determined by the trends of industrial development and logistics (production+logistics).

A systematic literature review shows many approaches of the literature in the field of just-in-time and just-in-sequence decision making. The developed research protocol allows us to get better knowledge, understanding and comprehensive review of the relevant literature in each research topic.

In the literature, it is also mentioned that there is fierce market competition to fulfil the market demands. Improvement can occur by rethinking the operations such as minimizing operational costs and responding to immediate customer needs.

Based on the above-mentioned approaches, in my dissertation I discuss the just-in-sequence supply systems development, their decision support model structure, their mathematical description, and the different supply strategies mathematical modelling for the improvement of optimal in-plant processes.

The development of the model structure allows to map some typical system variations of just-in-sequence supply systems for further testing. I have explored the background of the just-in-sequence model, which is able to describe the system parameters, the objective functions and the constraints on each supply tier that need to be considered when developing specific model variants.

Mathematical modelling of just-in-sequence supply strategies has made available optimal system parameters for supply under all three basic strategies in deterministic and stochastic environments. To verify the developed models, numerical analyses were carried out to investigate some fictitious companies' raw material supply processes. By evaluating and comparing these supply chains' indicators to determine which application of the model is preferable.

The results have represented the potential of just-in-sequence supply chain applications and optimization because these support the automotive and mechatronics companies' decision-making processes, especially in the management and control of manufacturing or service processes. As a possible validation of the developed models, I created an optimal procurement portfolio to evaluate the efficiency of manufacturing and supply processes' procurement and inventory management. As a result, the efficiency of inventory development can be observed, because the scheduling and delivery material flows can be controlled in just-in-sequence supply processes, while operating costs can be significantly reduced.

My further research goal is the development and application of new heuristic, and metaheuristic optimization methods for solving NP-hard problems based on the test models, which can design an optimal enterprise management system.

In my academic work, I would be pleased to apply my dissertation results to the education, because there is a necessity to transfer knowledge, nurture future intellectuals and to educate the next professional generation.

8. THESES OF THE DISSERTATION

THESIS I.

Based on the PDSA method in ISO 9004-4, I have developed a new systematic literature review protocol to increase the reliability of the literature review. This novel approach to the systematic literature search goes beyond descriptive analysis to a more rigorous set of criteria and requirements to examine the state of the literature on a given research topic.
As a result, I conclude that the literature review was carried out using the newly developed test protocol: the developed test protocol provides a comprehensive view of the design issues of just-in-time based just-in-sequence supply chain solutions – especially in manufacturing and service company supply processes.

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THESIS II.

I have developed a new model structure of just-in-sequence supply systems, which can be used to design some typical system variations for further investigation.
I have defined a mathematical model background for the just-in-sequence supply system, which describes the parameters of the overall systems and the single system elements.
I have described the system parameters, objective functions, and constraints for suppliers, warehouses, carriers, and manufacturers which must be considered when developing specific model variations.

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THESIS III.

I have developed a characteristic mathematical modeling framework of the just-in-sequence for all three basic strategies, which can be used to determine the optimal system parameters for just-in-sequence supply in deterministic and stochastic environments.
Numerical analyses have been used to evaluate and compare the indicators of just-in-time and just-in-sequence supply to determine where the model of the just-in-sequence supply is preferable.
I have defined the problem of just-in-sequence supply systems, which require the development and application of new heuristic, metaheuristic methods to solve NP-hard problems.

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THESIS IV.

I have developed a decision-support matrix model to evaluate the purchasing efficiency of manufacturing and supply processes.
I have examined the purchasing costs of product clusters related to each inventory strategy and concluded that which just-in-sequence inventory strategies are preferable.
Thus, the definition of an optimal purchasing portfolio is necessary for the development of a just-in-sequence supply chain, which contains the following main research sub-areas: (1) the minimalization of the level of stocks and materials, (2) increasing efficiency of inventory management activities, (3) solving decision making problems, (4) improving material flow intensity and (5) evaluating in aspects of natural and cost-based objective functions.

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