IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

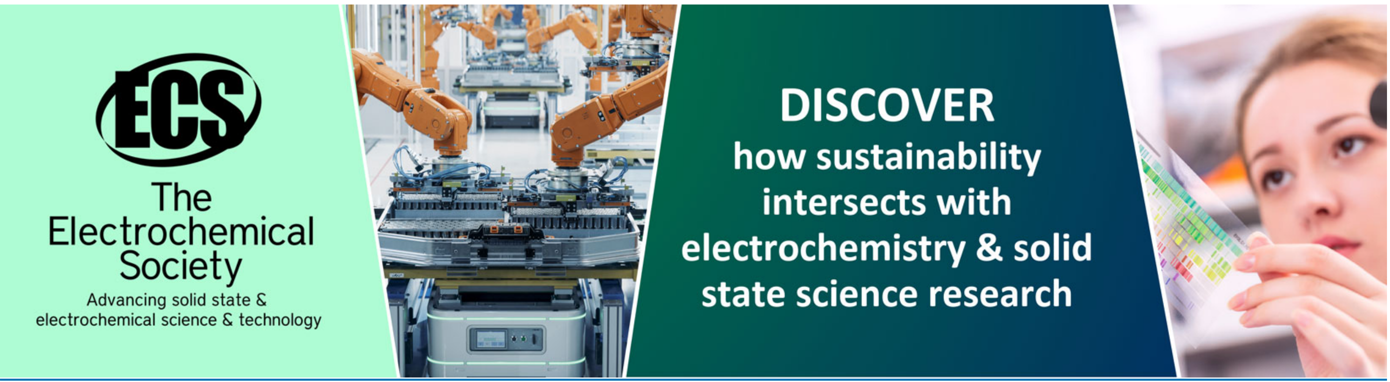
Logistic aspects of Industry 4.0

To cite this article: R Skapinyecz *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **448** 012014

View the article online for updates and enhancements.

You may also like

- Information Security and Adoptable Solutions in the Implementation of Industry 4.0 Strategy for the Fourth-generation Industrial Revolution
  Xiaolei Cheng and Pinghua Zhang
- How the Core Technologies of Industry 4.0 are Changing the Automotive Industry in the World, with a Focus on China
  Isak Karabegovi, Ermin Husak, Edina Karabegovi et al.
- Impact of the fourth industrial revolution on the sustainability of Vietnam's economic development
  Liudmila Guzikova, Lo Thi Hong Van, Igor Nechitaylo et al.



This content was downloaded from IP address 3.138.175.180 on 25/04/2024 at 16:44

IOP Conf. Series: Materials Science and Engineering **448** (2018) 012014 doi:10.1088/1757-899X/448/1/012014

Logistic aspects of Industry 4.0

R Skapinyecz, B Illés and Á Bányai

Institute of Logistics, University of Miskolc, Miskolc 3515, Hungary
altagota@uni-miskolc.hu

Abstract. Through the fourth industrial revolution, today such technological innovations and methods have become available which enable the development of complex logistics systems where the entire supply chain can be operated in an automated way. The aim of the study was to investigate how to increase the efficiency of logistics processes through the exploitation of the opportunities offered by the fourth industrial revolution. The paper presents the essence of Industry 4.0, the technological conditions of the fourth industrial revolution, its opportunities and challenges, and examines its impact on both intra-corporate and non-corporate logistics processes. We analyze the operational processes of logistics networks and the efficiency gains achieved through Industry 4.0 applications. Reliability and quality assessment of logistics networks are a complex problem. In this paper, we will present an innovative solution which is based on Industry 4.0 infocommunication solutions and the application of risk management and quality assurance tools, one that enables the optimal selection of logistics service providers in the network from a reliability point of view.

1. Introduction

The forthcoming fourth industrial revolution or otherwise Industry 4.0 means the accelerating growth of the efficiency of production systems. This includes online cyber-physical systems, the Internet of Things (IoT) and cloud-based solutions.

The fourth industrial revolution creates what we call the "smart factory". In modular smart factories, cyber-physical systems control physical processes that create an apparent copy of the physical world and make decentralized decisions. Objects, cyber-physical systems communicate over the Internet and interact with each other and with people in real time.

2. The fourth industrial revolution

An industrial revolution can be talked about when the efficiency of production systems is significantly increased due to a new technology solution. The design and operation of systems are becoming increasingly knowledge and resource-intensive, so a breakthrough can only be achieved by increasing the complexity of the systems [1].

The first industrial revolution mobilized the mechanization of production, using the power of water and steam, that is, the revolutionary developments were made possible by the emergence of mechanical production systems. The second industrial revolution, with the help of electricity, introduced mass production, followed by the digital revolution. During the third industrial revolution, electronics and information technology (IT) began to automate processes. Automation offered an alternative to the human work needed to operate, accelerating and decoupling the core manufacturing processes. It was this time when the first PLCs were released in the industry.

The fourth industrial revolution can be achieved because such technological innovations and methods have become available that enable the development of even more complex systems, where the entire supply chain can be operated in an automated way. This is based on cyber-physical systems that connect real objects with the processing of information. Cyber-physical systems can be

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

IOP Conf. Series: Materials Science and Engineering **448** (2018) 012014 doi:10.1088/1757-899X/448/1/012014

represented in many fields of engineering, like services [2], traditional [3,4] and networked manufacturing [5].

The prerequisite for these solutions is to create smart factories that have independent, shared intelligence and are in close contact with each other. By using detailed and interconnected models of elements, the complex system of these clever components can be optimized for comprehensive goals. To make this compilation work requires not only the "smart" elements to be networked, but also makes it necessary to coordinate these in a "cybernetic space". This is feasible with model-based optimization and development with the use of simulation tools.

In the future, the production process in the manufacturing network can be automatically adjusted to the urgency of incoming orders. According to the adaptive production, orders can be processed continuously and transferred to procurement and logistics systems. The operating network accordingly ensures the optimization of material and energy flow along the entire value chain. Intelligent machines continuously share information about current inventory levels, issues, errors, and the changes in demand. In process management, the goal is to increase efficiency, optimize lead times and increase capacity utilization [6]. Table 1 illustrates the fundamental differences between today's factory and the factory of the future.

Table 1. Comparison of today's factory and the factory of the future [6].

		Today's factory		**Factory of the future**	
	data source	**main characteristics**	**main technologies**	**main characteristics**	**main technologies**
compo-nent	**sensor**	precision	smart sensors and failure detection	knowledge of own operations, predictive ability	monitoring of all features, life expectancy forecasts
machine	**controller**	manufacturability and performance	state-based system monitoring and diagnostics	knowledge of own operation, predictive ability, comparability ability	real-time preventive status indicators
manufac-turing system	**networked**	performance and total asset efficiency	Lean operations: work and waste reduction	self-configuration, self-maintenance, self-organizing ability	risk exemption, performance

The factory of the future will produce products in an intelligent and fully integrated way, flexibly and efficiently. Separate and autonomous applications will form a unified system in an integrated network. Decentralization takes place in decision processes and enables real-time autonomous decisions at machine level and flexible decision-making about the production processes based on timely data. This requires the rethinking of the traditional business approaches and solutions. Better monitoring of products and production processes can also increase the relationship with suppliers, and controlling and financial planning can also provide greater precision, thus making more informed decision-making. Changes will be enforced by growing customer expectations, and companies will need to provide quick and tailor-made responses to these changes [7].

Cyber-Physical-Productive Systems (CPPS) do not only incorporate production tools into intelligent networks, but integrate the entire supply chain. Clever production tools share information about their utilization and status (for example, maintenance) and decide on their own issues independently. Shared information is achieved by using simulation and optimization tools, and optimally, in a completely independent manner. In order to increase efficiency, utilize capacities, reduce resources, improve quality and reduce lead times, the goal is to coordinate processes [8].

Cyber-Physical Systems are able to collect data from their environment using sensors and act after analyzing their situation [9]. Cyber-physical systems are networked, a significant part of them are interconnected, so it is possible to use swarm intelligence (the application of a common strategy in operation), which results in even more efficient operation (Figure 1).

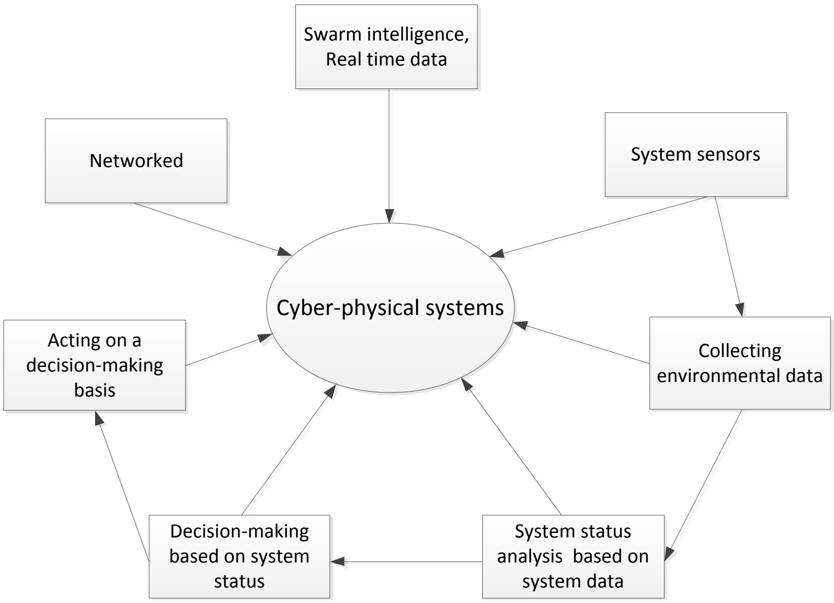


Figure 1. Cyber-Physical Systems [9].

The fourth industrial revolution has many advantages for economic operators, but at the same time, companies have to face many problems during its implementation.
Challenges in Industry 4.0:

- The security problems of information technology (IT) are greatly aggravated by the reuse of previously completed projects.
- The need for reliability and stability for critical machine-to-machine communication (M2M) including very short and stable waiting times.
- The integrity of production processes must be maintained.
- Avoid any unforeseen obstacle to information technology that can cause expensive production downtime.
- Industrial know-how must be protected.
- There is a lack of appropriate expertise that would speed up the progress towards the fourth industrial revolution.
- Redundancy in information technology (IT).
- It is difficult for affected parties to change.
- Automated and IT-driven processes result in the loss of jobs, especially in the lower-tier social strata.

It is an important hindering factor for the spread of industry 4.0 achievements that standards, norms and certificates are not yet available to ensure the interconnection of different systems. The core technologies of the digital infrastructure are still slowly spreading and are not necessarily available in any supplier or customer organization, so cooperation may be limited. Data security is a critical point for development.

Access control must be ensured, as well as the security of the network, the devices, the sensors, etc., together with the proper encryption of information. The production of smart products requires a new kind of technology, skills and processes throughout the entire value chain[7]. The company needs to realistically see what capabilities it can develop itself and when it needs to involve an external partner.

3. Impact of the fourth industrial revolution on logistics

The expansion of the important role of logistics in the economy is significantly supported by the rapid and dynamic development of informatics and cybernetics. The emergence and application of cyber-physical systems in the logistics processes leads to further significant changes in the operation of the economy. Of course, it should not be forgotten that logistics is a human-machine-based system based on material handling machines, machine systems, IT systems and networks, the techniques and technology of these and the appropriate standard of human vocational training.

Current trends in logistics are influenced by changes in the economy and society. The most important parameters affecting the economy are illustrated in Table 2.

Table 2. The most important parameters affecting the economy.

Changes in the market and in production	Globalization and localization
	Distributed intelligence based network systems
	Different solvency market needs
	The development of informatics and information technology
	Product structure change
	Decrease in production depth
	Decrease in Product Lifecycle
	Decrease in product ranges
	Concentration on core activity
	Make or buy philosophy
	Outsourcing activities
	JIT-based deliveries
	New interpretation of quality

Regarding the development of informatics and information technology, we need to highlight digitalization, which has fundamentally changed the market expectations and opportunities for logistics. In the field of logistics, the diversity of products being handled, the new techniques and technologies introduced in production and service, the operation of the various networks and the need for globalization make it necessary to increase the complexity of logistics systems while ensuring the transparency of such systems. This can be solved only with automated and optimized complex structures, processes, and subprocesses.

When designing these types of systems, the various cyber-physical systems play a decisive role. The operation of a complex logistic process is influenced by a variety of parameters. Real-time values of the parameters can be collected by sensors. By gathering as much information as possible about the operation of the system, digitalizing these and applying real-time evaluations the real state of the system/constituent can be determined. Using the right choice of optimization method, the best way of intervention between the real state of the system and the possible decision set can be implemented in the logistics system. The system or system element can be networked. Through digitalization, a large amount of real data can flow between systems and system elements, which provide the optimum operation of a complex system when the proper operating strategy based on the given criteria is applied [10].

In the next period, digitalization completely transforms the economy and life of the whole human race. In the area of production and services, more and more operational parameters of logistics activities become accessible, while in the frame of "the Internet of Things", the ensuring of the management of data sets results in the strengthening of the customer controlled activities in logistics services. In the field of logistics, digitalization takes place in the direction of standardized relationships instead of individual relationships and individual business processes, then towards the direction of the development phase of bidirectional direct connections and the provision of highly flexible, large-scale information access to external partners through integrated connections.

When examining the impact of Industry 4.0 on logistics, we have to take care of both intra-corporate and non-corporate logistics processes. The planning, design and operation of intra-corporate logistics processes are significantly influenced by the achievements of the fourth industrial revolution, allowing companies to track customer needs and procurement orders in real time. Based on these, they can plan their own capacities and resources to prepare for receiving and storing the components about to be delivered, and for the steps and demand of serving the production. In the case of distribution logistics, the basis for planning the finished product stocks, the warehouse locations and the deliveries is again provided by the production plan. Thus, logistics capacity planning can be realized at the same time as production planning, relying on the real-time data from the latter. Thanks to the automation, robotization, and development of logistics processes based on Industry 4.0 technology, the performance of the personnel performing logistics operations can be increased or, where appropriate, replaced.

Freight transport is a critical point for logistics processes outside the company. Using the achievements of the fourth industrial revolution, significant efficiency gains in freight transport can be achieved. Sensors built into products ensure product tracking, fix shipping conditions, facilitate identification of goods at loading and unloading, significantly reducing their time. Logistics processes, including freight transport, are fundamentally altered by the appearance and spread of driverless vehicles. These devices have many benefits: they will make transport safer, fuel consumption and pollution will be reduced, while there will be no need for mandatory rest periods for carriage which increase downtime, thus reducing lead times. Many other factors in road transport will also change with the emergence of autonomous vehicles: transport distances will be shortened due to the relocation of production; reduced shipping rates and consequently increased frequency; city logistics is more emphasized; Drivers can avoid traffic jams by using RFID technology and intelligent applications; applications will suggest the best route based on user community information rather than on GPS data; smart solutions improving road safety will be further developed.

3.1. Increasing the efficiency in logistics networks

The digitalization and transparency of production processes create the possibility for the procurement to rely on the prepared forecast and production plan, and based on these obtain the necessary raw materials and sub-assemblies. With the help of plans and production information that are constantly up-to-date based on real-time data, it can be accurately calculated that how much raw materials will be needed and where, which can increase the performance of the company's procurement logistics system. Further efficiency gains can be achieved through the integration and coordination of activities within and between companies, which is the essence of the supply chain approach (Figure 2).

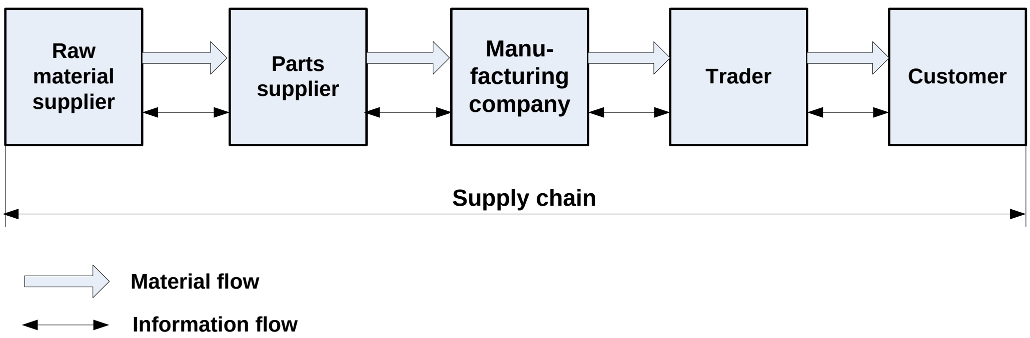


Figure 2. Material and information flow in the supply chain.

Nowadays, not isolated companies, but rather more or less co-operative supply chains compete with each other in order to meet the customer needs ever more efficiently. The need to organize supply chains is justified by the increase in the economic role of supply [11].

One of the most cost-effective solutions to enhancing competitiveness and reducing inventories is provided by networking and network-like operation. Today, due to the complexity of the supply chain, it is more appropriate to use the term of a supply network, since chain members must build a complex network of activities to produce a single product. Accordingly, the supply chain is a process chain of the network along which the product can be traced from the supplier to the final consumer. Thus, the processes go beyond the boundaries of the company, the goal is to enhance the overall chain performance.

Tracking a cross-company relationship system is a very difficult task. Appropriate and quick response to any mistakes on the market is a great advantage as costs can be better planned. The collection and processing of good quality data in appropriate quantities requires a high level of IT and automation. Industry 4.0 provides an effective solution to this problem, as in addition to manufacturing systems, it aims to increase the efficiency of supply networks as well [12].

It assumes high level of flexibility and transparency in real time, in other words, the operation of real-time optimized new value creation networks. The smart factory adapts to the new circumstances of its environment at all times and optimizes the production processes by itself. The sharing of information on the production systems is assumed by this concept, which requires the development of a new business model for cooperation between organizations. This is achieved through integration with suppliers and customers in the value chain. The new business models should focus primarily on developing new collaboration models with business partners and handling customer specific expectations, which will require new forms of information sharing with customers and suppliers. It is important to mention that continuous communication is required throughout the product's lifecycle, i.e. the management of customer requirements, research and development, procurement, production, and market data all have to be covered. Smart products have information on their own manufacturing processes and collect and transmit data from the production and use phases of their life cycle. The development of smart logistics systems, in addition to information supply over the supply chain, means the development of independent and flexible external and internal logistics solutions.

The quality of the relationship between members of the supply network is basically determined by the use of integrated information systems and advanced forecasting methods. The effectiveness of the link depends on the accuracy of the sales information provided by the buyer and the supplier's willingness to keep the inventory:

$$M_h = f(I_m;\ K_k) \tag{1}$$

where

M_h - the effectiveness of the link between members of the network,

I_m - the quality (accuracy) of the sales information provided by the buyer,

K_k - the inventory keeping ability of the supplier.

Based on the above, we can state that the level of cooperation between the members of the network can be increased by providing the supplier with more accurate sales information from the buyer, as the supplier's willingness to maintain the inventory increases in a straightforward manner.

4. Increasing efficiency through the optimization of logistics networks

Ensuring the proper operation of modern factories today is almost unimaginable without the existence of such logistic systems which operate in a harmonized manner with the production processes. This is even more true for smart factories resulting from the fourth industrial revolution, where real-time product tracking and JIT (Just In Time) principles are virtually binding on both the delivery and distribution sides. In order to ensure the above conditions, logistics service providers involved in the supply chain must, of course, have to meet a number of often difficult to quantify quality requirements. As a result, the performance assessment of modern, multi-player logistics networks is a distinct complex problem. In the followings, an example for an advanced methodology will be presented, one that makes possible the optimal selection of logistics service providers in the network from a reliability point of view, building on the infocommunication solutions of Industry 4.0 and on the tools of risk management and quality assurance.

One of the key pillars of the methodology that is going to be presented is the application of the process capability concept. The concept of process capability is derived from statistical process control (SPC), which first appeared in the 1920s and 30s in the field of manufacturing and has now become one of the essential tools of quality assurance at a large number of production companies. It is important to emphasize that the process capability approach is increasingly being used in the service sector as well, especially as part of Six Sigma, so its use is also gaining momentum in the field logistics [13]. This is supported by the increasingly wider range of logistics applications of Six Sigma, in particular within supply chains [14-19].

The concept of process capability is based on the recognition that fluctuations in characteristic parameters of industrial processes can usually be described by means of normal distribution (where this is not achieved, the approach can generally still be applied after appropriate normalization). This also means that from a sufficiently large sample of the relevant parameter in the process, the standard deviation (σ) and the expected value (μ) for the parameter can be deduced. The essence of the concept is that the statistical indicators thus obtained are compared to the technically permissible limits for the relevant parameter (LSL - lower specification limit, USL - upper specification limit), thereby giving an accurate picture of the future performance of the process. From a practical point of view, the so-called critical process capability (c_{pk}) is particularly important, which is defined by the following relationships [13]:

$$c_{po} = \frac{USL - \mu}{3\sigma} \tag{2}$$

$$c_{pu} = \frac{\mu - LSL}{3\sigma} \tag{3}$$

$$c_{pk} = min\{c_{po}; c_{pu}\} \tag{4}$$

The central idea of the procedure being presented is that with the knowledge of the right historical data, a cumulative critical process capability index can be calculated for any arbitrary combination of logistics service providers and logistics processes. The goal is to select the provider-process combination in such a way that this value is maximized. This is mathematically expressed by the following goal function:

$$kc_{pk} = \sum_{j=1}^{m} \frac{q_j \cdot p_j}{P} \cdot \sum_{i=1}^{n} \sum_{k=1}^{r} c_{pk}(i, j, k) \cdot pr_k \cdot x_{ijk}^{stk} \rightarrow Max \tag{5}$$

The meanings of the variables which are present in the goal function are the following:

- q_j: the quantity of the goods that has to be handled in the *j*-th process,
- p_j: the average value of a single unit of the goods which has to be handled in the *j*-th process,
- *P*: the total value of the goods which are going to be handled in the examined processes during the relevant time interval: $\mathrm{P} = \sum_{j=1}^{m} p_j$
- $c_{pk}(i,j,k)$: the calculated value of c_{pk} for the *j*-th process at the *i*-th provider in relation to the *k*-th risk parameter,
- pr_k: the weight of the *k*-th risk parameter (this can be determined with the use of the risk model which is going to be presented later),
- x_{ijk}^{stk}: the binary decision variable that is used for the selection of the relations included in the solution (from this, it can be seen that the problem in this form esentially can be solved with the use of linear programming).

From the foregoing, it can be seen that, for the application of the outlined concept, a great deal of historical data is needed, which are primarily necessary for the determination of statistical parameters. Furthermore, it is necessary to collect these data both from the service providers and from the production companies (which fulfill the role of clients) in the network, thus assuming the application of a network model based around information sharing. The scope of the information to be collected, processed and produced in connection with the procedure and the relationships between the data objects are presented in the following data model (Figure 3):

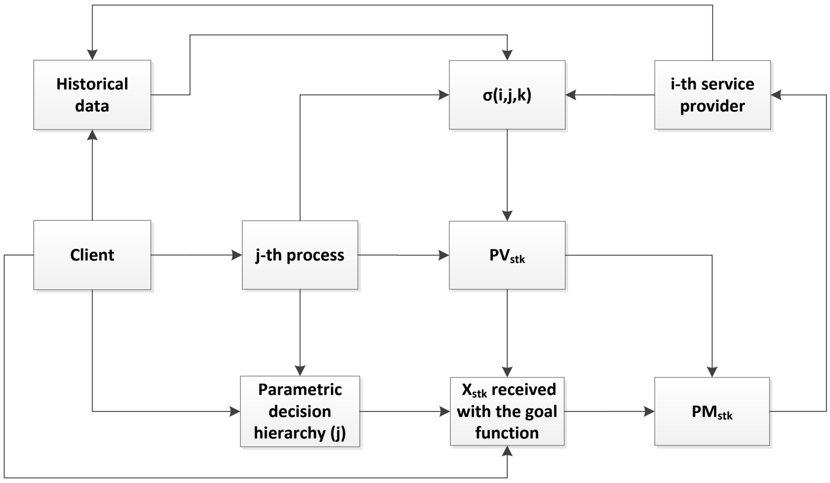


Figure 3. High-level data model defining the information sharing model.

The data model includes the following types of data objects and their relationships:

- Client type data objects represent the production companies that use the system. The information to be obtained from them is mainly necessary to determine two other data object types, the logistic processes and the parametric decision hierarchy (the latter will be discussed later).
- The j-th process data objects are assigned to the clients. The main data elements of the data type are naturally the tolerance intervals which the client sets for the process in relation to each risk parameter.
- The Parametric Decision Hierarchy data object can be considered as a hierarchical data model itself, which forms the risk model within the procedure. Essentially, it is a decision model created by using the AHP (Analytic Hierarchy Process) method. The parameterization of the model can be carried out by the particular client, thus enabling the procedure to be widely applicable (later the actual decision model itself is also going to be presented).
- The i-th service provider type data object corresponds to the *i*-th service provider that joins the system. Among the information related to the service provider, the most important are those $\sigma(i,j,k)$ standard deviation values which characterize the given service provider from the aspect of maintaining the *k*-th parameter of the *j*-th process. These are also necessary for calculating the respective $c_{pk}(i,j,k)$ values.
- σ(i,j,k) is both connected to the i-th service provider and the j-th process data objects, and hence itself has been represented as a separate object. Determining the value of $\sigma(i,j,k)$ can be done in two ways, from which the simpler solution is possible if the provider has already provided the process. If this criterion is not met, or simply because of the nature of the parameter *k*, a greater amount of data is needed, than the value of $\sigma(i,j,k)$ can be also calculated on the basis of the existing σ values of the other processes in the same category at the given service provider.
- The Historical data object contains all the data (past values of the relevant logistics parameters), based on which the value of $\sigma(i,j,k)$ can be determined for each service/ process/risk factor relation.
- The PV_{stk} data object represents a three-dimensional matrix that contains the relevant c_{pk} (i,j,k) values for each provider/process/risk factor relation (that is, the critical process capability that can be achieved in a particular relation).
- The X_{stk} received with the goal function data object contains the provider/process/risk factor relations that have been selected using the goal function (the data object here is also a three-dimensional matrix, but its elements in this case are binary values).

- Finally, the PM_{stk} data object contains the $c_{pk}(i,j,k)$ values for the selected provider/process/risk factor relations (therefore it is also a three-dimensional matrix).

As mentioned several times, the weighting of each risk factor in the target function is determined using a separate risk model that was created using the AHP method. AHP itself is one of the most widely used decision making methods that is widely used in a number of areas, including logistics, with particular regard to supplier, site and route selection [20-22]. In the current procedure, the purpose of setting up the AHP model was therefore to determine the weighted ranking of the risk factors for the particular client. The basis for the comparison is the question of how much the individual risk factors contribute to the realization of the additional risk costs on the side of the client, from the aspects of each decision criteria? The structure of the decision hierarchy, i.e. the risk model, is shown in Figure 4:

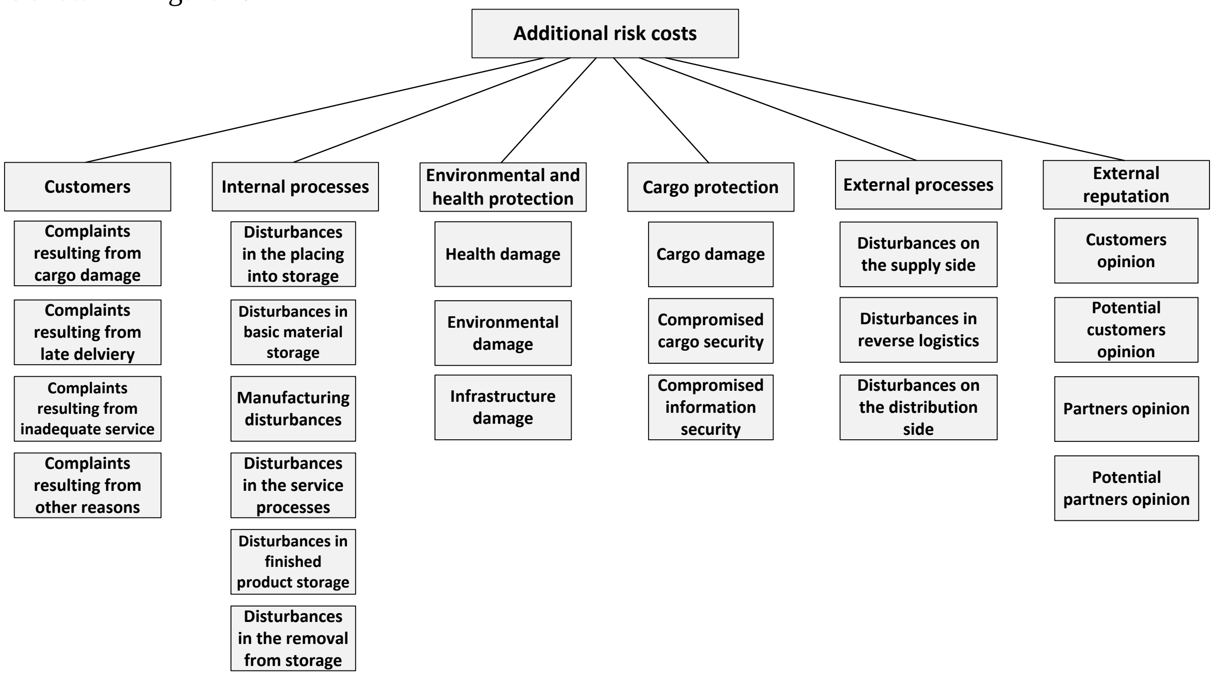


Figure 4. The risk model implemented as a decision hierarchy.

As can be seen from the foregoing, the process outlined above thus largely builds on information sharing between the parties involved in the logistics network. Of course, the use of Industry 4.0 infocommunication solutions is necessary in order to implement the required level of information exchange. One of the most promising foundations in this respect could be the so-called RAMI 4.0 - Reference Architectural Model Industrie 4.0 - concept, which has been recently developed by participant organizations of the Platform Industrie 4.0 in Germany. RAMI 4.0 basically identifies six main horizontal layers, which are from top to bottom: the "Business" layer, the "Functional" layer, the "Information" layer, the "Communication" layer, the "Integration" layer, and the "Asset" layer. For the outlined process, the most important issue is, of course, the implementation of the Information and Communication layers. As can be seen in Figure 5, one of the most obvious solutions for this is the use of the OPC UA - Open Platform Communications Unified Architecture - standard. It is very important that OPC UA is an existing standard that allows a wide range of industrial equipment to be interconnected (the specification is found in IEC 62541). Another advantage is that it is also a widely applicable standard, thanks to the applicability of companion specifications and extended information models. It is also very important that OPC UA is compatible with both the IPv4 and IPv6 standards. For these reasons, it could be useful in many ways to apply it to logistics systems that work in accordance with the Industry 4.0 concept. In case of the described methodology, it may offer a particularly advantageous solution for the sharing of information between the actors in the logistics network. The communication patterns of OPC UA are illustrated in the following figure [23].

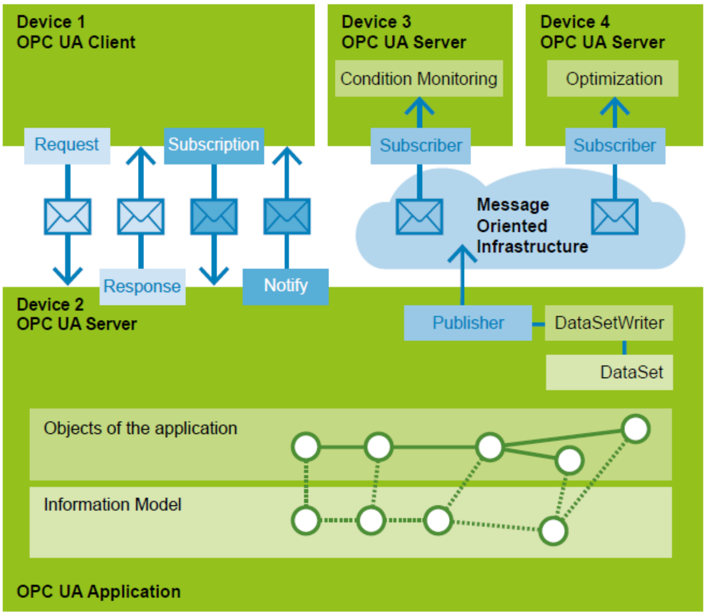


Figure 5. OPC UA Communication Patterns [23].

All in all, it can be stated that RAMI 4.0 and OPC UA could already jointly offer solutions to the application of the presented procedure in an Industry 4.0 environment. At the same time, it is also important to note that the development of the process was justified by the fact that the high degree of digitalization and extensive information sharing, which go hand in hand with the Industry 4.0 concept, will require the use of such risk management tools in logistics networks that can facilitate effective decision-making based on an increasingly large number of data.

5. Summary

Today, due to increasing complexity in supply chains and uncertain supply and demand, ensuring flexibility in future supply chain planning will be one of the most important tasks. One of the most important prerequisites for supply chain flexibility is the development of network-based collaborations and the use of Industry 4.0 developments.

The study analyzed the operational processes of logistics networks and examined how the efficiency of logistics processes could be increased by exploiting the opportunities offered by the fourth industrial revolution. Based on Industry 4.0's infocommunication solutions, we introduced a methodology that allows the optimization of logistics networks using the tools of risk management. During the development of the presented research work, we have set the goal of developing a risk management process that is suitable for optimally assigning the service providers and the logistics processes to each other within a given network from a risk-based perspective.

Acknowledgments

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691942. This research was partially carried out in the framework of the Center of Excellence of Mechatronics and Logistics at the University of Miskolc.

6. References

[1] Heng S 2014 Industry 4.0: Upgrading of Germany's Industrial Capabilities on the Horizon https://ssrn.com/abstract=2656608

[2] Kása R, Gubán Á, Gubán M, Hua N S and Molnár L 2014 The concept of perception driven service process reengineering by entropy reduction *Pannon Man Rev* **3**(1) 11-54

[3] Kundrák J, Deszpoth I and Molnár V 2014 Comparative study of material removal in hard machining of bore holes *Tehnicki Vjesnik* **21**(1) 183-89

[4] Kulcsár G and Kulcsárné Forrai M 2013 Detailed Production Scheduling based on Multi-objective Search and Simulation *Prod Sys and Inf Eng* **6** 41-56
[5] Bányai T 2002 Clusters vs virtual enterprises *Mechanics and Mechanical Eng* **6**(2) 17-24
[6] Lee J, Bagheri B and Kao H A 2014 Recent Advances and Trends of Cyber-Physical Systems and Big Data Analytics in Industrial Informatics *Proc. Int. Conf. on Industrial Informatics* (Porto Alegre) (IEEE)
[7] Nagy J 2017 Industry 4.0: definition, elements and effect on corporate value chain http://unipub.lib.uni-corvinus.hu/3115/
[8] Abonyi J and Miszlivetz F 2016 Intersections of networks: Social challenges of I4.0 (Szombathely: Savaria University Press)
[9] Tamás P and Illés B 2016 Smart logistics in manufacturing *Gépgyártás* **55**(2) 51-6
[10] Illés B, Varga A K and Czap L 2018 Logistics and digitization *Lect Notes in Mech Eng* **2018** 220-25
[11] Szegedi Z 2012 Supply chain management (Budapest: Kossuth Kiadó)
[12] Nagy G, Bányai Á, Illés B and Glistau E 2018 Analysis of supply chain efficiency in blending technologies *Lect Notes in Mech Eng* **2018** 280-91
[13] Illés B, Glistau E and Machado N I C 2007 *Logistik und Qualitätsmanagement* (Budapest: Budai Nyomda) p 195
[14] Garg D, Narahari Y and Viswanadham N 2004 Design of six sigma supply chains *IEEE Trans on Autom Sci and Eng* 38-57
[15] Narahari Y, Viswanadham N and Bhattacharya R 2000 Design of synchronized supply chains: A six sigma tolerancing approach *Proc Int Conf on Robotics and Automation* (IEEE) 1151-56
[16] Christopher M and Rutherford C 2004 Creating supply chain resilience through agile six sigma *Critical eye* **24** 28
[17] Knowles G, Whicker L, Femat J H and Canales F D C 2005 A conceptual model for the application of Six Sigma methodologies to supply chain improvement *Int J of Log: Res and Appl* **8**(1) 51-65
[18] Dasgupta T 2003 Using the six-sigma metric to measure and improve the performance of a supply chain. *Total Quality Management and Business Excellence* **14**(3) 355-366
[19] Lee M-C and Chang T 2010 Developing a lean design for Six Sigma through supply chain methodology *Int J of Prod and Qual Manag* **6**(4) 407-34
[20] Vaidya O S and Kumar S 2006 Analytic hierarchy process: An overview of applications *Eur J of Oper Res* **169**(1) 1-29
[21] Ho W 2008 Integrated analytic hierarchy process and its applications–A literature review *Eur J of Oper Res* **186**(1) 211-28
[22] Sipahi S and Timor M 2010 The analytic hierarchy process and analytic network process: an overview of applications Manag Dec **48**(5) 775-808
[23] VDMA 2018 Industrie 4.0 Communication Guideline Based on OPC UA https://industrie40.vdma.org/documents/4214230/20743172/Leitfaden_OPC_UA_Englisch_1506415735965.pdf/a2181ec7-a325-44c0-99d2-7332480de281