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LOGISTICS INFORMATION PROCESSING SYSTEMS ON THE THRESHOLD OF IoT

Summary. This paper presents in general, the issue of logistics information and systems processing it in logistics chains. The concept of logistic information was defined and the main types were discussed, with particular emphasis on information associated with logistic facilities, such as warehouses. Thereafter, a three-level model of the information processing system in the logistics chain was presented and elaborated upon. The importance of new, primary concepts in the field of logistics information – Logistics 4.0 and Internet of Things as well as the resulting concept of decision centres scattered to the equipment layers of logistic systems were reviewed. The summary contains probable development trends in the five most important areas of logistics information processing in the future.
Keywords: logistics information, internet of things, logistics 4.0

1. LOGISTICS INFORMATION

Logistic information is next to the material flows, a foundation of logistic processes. Each material flow is associated with at least three information flows. It must be preceded or triggered by information; information accompanies it, and information ends (confirms) it.

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This rule applies to all kinds of material flows, starting with simple movements of packages on the assembly line and ending with large scale contracts proceeded by logistics networks.

Subsequent space transformations (transport), time transformations (buffering and storage) and shape-related transformations of material streams in logistics chains determine type and content and increase the amount and variety of information.

Logistics information is defined as information useful in logistics management and control. It can simply be divided into information transformed separately from the material stream (triggering and ending, tracking, accounting and recording) and transformed together with the material stream (mostly identification). In most cases, information accompanying materials is doubled by information transformed separately, since the origins of all labels an identifiers stuck into physical units are somewhere in the structure of information management system.

Information, from its definition, describes the essence and nature of object or phenomenon [16]. Logistics information relates to knowledge, news, and data (facts) [12]. Data is meaningful, repeatable information representing values attributed to parameters, news inform about single, but significant events or phenomena influencing supply chain, and knowledge is for the understanding of concepts. Logistics information can be more precisely represented by three categories involved in the different management levels in the logistics chain (or network) (Fig. 1).

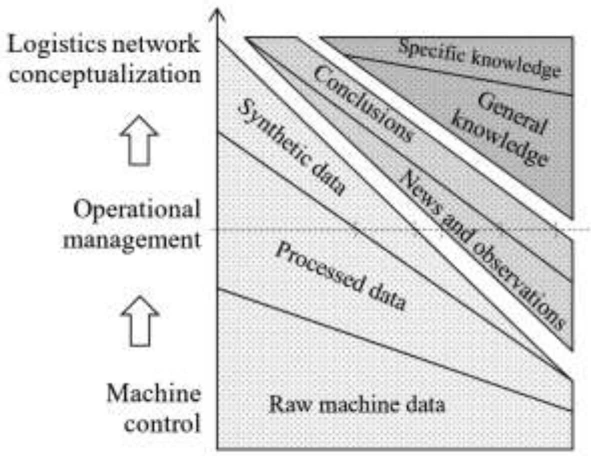

Fig. 1. Logistics information map

All three general categories of logistics information presented in Fig. 1 are necessary and concomitant in logistics chain management. A large variety of types of information and processing schemes impose standardisation to allow proper interpretation and processing information by decision-makers at all management levels in a logistics chain. The variety of logistics information results from a wide spectrum of material flows transformations in logistics systems. This information cover concepts and strategies, trade relationships, logistics features of handling units and resources of all types, tracking, payments and accounting, client services, marketing, catalogues and production engineering, insurances and legal regulations, operational data, machines data, and many other.

Most logistics data are generated, gathered, processed and concluded to gain general knowledge on operational management and logistics system conceptualisation [7]. However, there is another part of data, which despite being collected, will never be used for management or control purposes. Referred to as dark data, it is acquired through various information systems but not used in any manner to derive insights or for decision-making. It is estimated that about 50% of data gathered in logistics systems is dark data [14]. Most of the data will not have a chance to become dark data because it is not stored in any way. To deal with this, new more efficient methods of big-data analysis are applied to dig dark data and make them useful for logistics process management [8, 17, 27].

All these observations refer to current logistics information-processing systems. Nevertheless, new concepts, like Industry 4.0 and resulting Logistics 4.0 with a flagship idea of the Internet of Things (IoT) announce demand for even more differentiated information and unpredictable amounts of data to be generated.

2. LOGISTICS FACILITY AS A DATA GENERATOR

The logistic facility is a nodal element of logistics infrastructure. Typically, logistics facility can perform as a warehouse, distribution centre, and terminal or production plant. Logistics facilities use a wide spectrum of data from internal and external sources [10]. These data are in the largest part related directly or indirectly to material flows and material stream transformation. Logistics facilities, especially those managed by complex warehouse management systems (WMS) are data-extensive and require high-quality data to control material flows and measure efficiency [1]. Most typical data generated and used by logistics facilities include:

- master data (item master data) – data of products handled in the facility including physical, biological, and chemical features, trade and stock data and other data required by superior information system like enterprise resource planning (ERP) or other,
- purchase order data, sales order data (order master) – data on the structure of received deliveries and shipments carried out from logistics facility of different granulation (mostly resulting from requirements of financial management systems),
- data on physical structure – especially on types and characteristics of physical locations (addresses) in the facility and their position in space,
- work resources data – types and numbers of human, mechanical and automatic resources, performance parameters and cost characteristics,
- standardisation and packaging – hierarchy of logistics units and packages used in the system,
- identification and coding – databases of identifiers for graphical (bar codes) and electronic coding (electronic product code, ECP) of information accompanying materials,
- history of material movements – history of timestamps of operations and actions performed on material units in the facility recorded in databases,
- history of resource usage – history of timestamps of operations and actions performed by technical resources and workers, recorded in databases.

Especially, the last two elements are interesting in the aspect of data generation and collection [25, 23]. These are internal sources of data produced by material handling systems (MHS) and control systems, starting from streamed automatic sensor data to forklift operator login to WMS. The data are used for ongoing control but usually are not archived if the supply chain does not require material tracking or only most important messages are kept. Besides, a typical warehouse produces gigabytes or terabytes of data daily.

Exemplary sizes of databases used in logistics facilities may use about 50 bytes per line. The number of lines can range from 2,000 to 8,000 lines per day for an active facility and to more than 80,000 or more lines per day for the most active facilities [2]. The item master data can embrace 20,000 to 100,000 stock keeping units (sku) for pharmaceutical distributor, up to 300,000 skus for car parts distributor and up to 500,000 sku for large electric parts distributor or hundreds of millions of skus in the whole Amazon company [19].

Repeatable data entries, histories of material movements, are lined with operational data resulting from decision-making process basing on knowledge and permanent information frame of the facility given by strategy and long-term plans.

3. INFORMATION NEEDS IN THE LOGISTICS CHAIN

Logistics chains are information-intensive structures producing data at three basic levels of organisation (Fig. 2). The first level is a general (business) management level in the logistics chain. Information at this level embraces commercial and strategic planning in the long-time horizon. This information is based on knowledge, conclusions and synthetic data depicted in Fig. 1. Enterprise resource planning (ERP), and other high-level, integrated informatics systems placed at this level, are focused on general planning and decision-making, processing business information to coordinate the supply chain, and link clients with the supply chain environment.

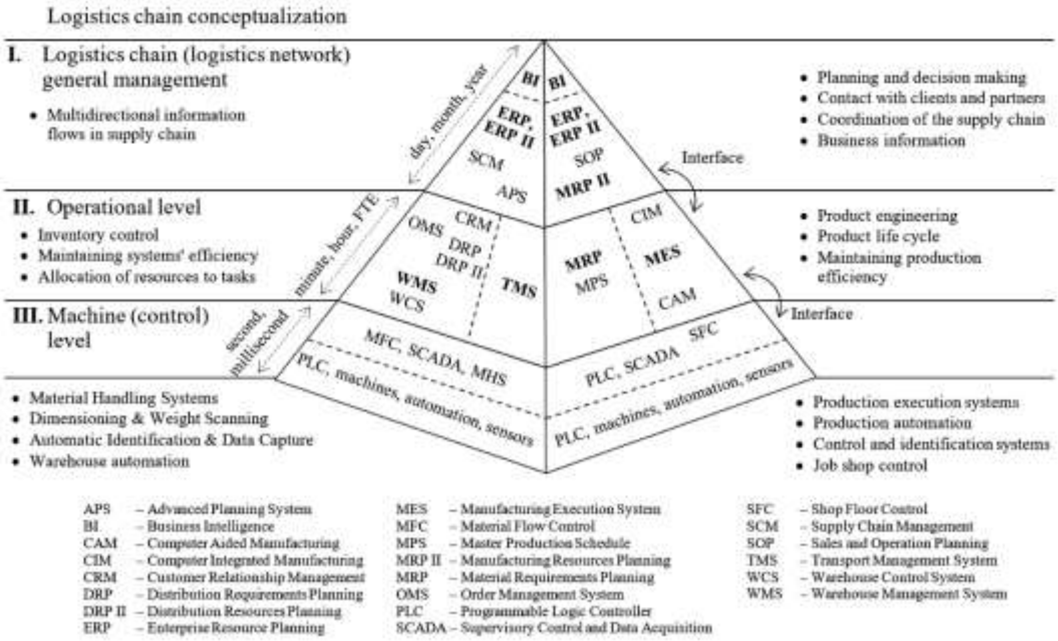

Fig. 2. General view on logistics information systems

The second level is for operational management, mostly occupied by solutions of the following types: warehouse management systems (WMS), transport management systems (TMS) and production control and management systems (Fig. 2). At this level, information systems support operational tasks in short-time horizon, and their work essentially consists of immediate response to the commands issued from the superior systems on the first level.

These systems are not primarily designed to make decisions, but rather to implement specific decision algorithms set in the implementation phase.

The third level is for machine and equipment control and serves as an executive layer of the second level. In logistics facilities, it is represented by a variety of automatic material handling systems, identification, and data capture systems, job shop control systems, and all solutions directly implemented at the floor of the logistics facility. The third level directly generates raw data (Fig. 1), which after processing can support decision making at higher levels.

Presented scope of functionalities of information systems in logistics chains is *extremely brief* and presents only the *general concept* of information processing. The information solutions listed in Fig. 2 form a complex software environment and data space with various, often overlapping, functionalities. The last ten years showed that these functionalities and data flows change and gravitate towards the ideas of Logistics 4.0 and Internet of Things.

4. LOGISTICS 4.0 AND INTERNET OF THINGS – SCATTERED DECISION MAKING

Logistics 4.0 is an offshoot of the Industry 4.0 concept discussed and observed for over 10 years. Logistics 4.0 simply moves the Industry 4.0 assumptions to the logistics ground and becomes a new logistics paradigm – foundation of information processing in distribution and production systems [24, 15]. It intends to create intelligent supply chains through advanced network communication covering all three organisation levels (Fig. 2) and information processing technologies.

The existing information structures, such as those shown in Fig. 2, in the first phase of Logistics 4.0, become the environment for *intelligent* technologies and data sources, but in the next phase will have to be transformed into systems compliant with the requirements of Logistics 4.0. Logistics 4.0 postulates applying “intelligent” technologies all over the supply chains and logistics networks for the final transformation of local structures into a distributed global logistics network using effectively shared resources and information. These technologies include intelligent buildings, vehicles, containers, equipment, pallets, locations, transport systems and, above all, information processing systems [3, 5, 18, 28]. Intelligent solutions in the first phase of Logistics 4.0 are necessary to create end-to-end network supply stream (E2E) in which the logistics process can be tracked and understood completely from every place in this process [4, 26]. Process transparency will improve the quality of decisions and planning mechanisms, and thus, the efficiency and quality of services.

Intelligent technologies in logistics require spread information processing centres installed on equipment and in locations, however, performing not only local functions but also tracking supply chain activities at the highest level of detail for further E2E capability. Full E2E combined with reliable data and “intelligent” processing are necessary elements of *anticipatory logistics* [4] in which the supply chain is not planned on the base of analysis of historical flows and market trends, but is fitted to needs in real-time, in some ways anticipating (or even creating?) future logistics tasks.

Internet of Things (IoT) reveals as a perfectly matched Logistics 4.0 tool. The IoT concept can be defined as direct or indirect data collection, processing and exchange by *things* in their surroundings [3-5, 18]. The logistics facility is a natural place to implement IoT since it is for handling materials – things in the space. Equipping things with sensors, computation and communication capabilities creates the abovementioned intelligence in logistics chains and fosters E2E. Switching the role of logistics (or production) equipment layer from simple handling tools and sensors filling up data silos with shadow data into communicated decision-making units is a trend in information processing in logistics facilities [5].

Implementation of IoT allows scattered decision making in logistics system, which is shifting the decision burden from higher levels of information systems to lower levels (Fig. 2). Centralised decision-making or data analysis system always has limited computing power, limited data resources and priorities that do not allow detailed consideration of lower-order problems. These factors limit the field of view and analysis provided by those systems and make it more general. To deal with lower-level problems, subordinated information systems must be included (like the second and third level in Fig. 2). However, the border is on the equipment layer. In current solutions, equipment layer is only a passive executor of fixed and inflexible procedures. IoT implementation equips this layer with the ability to observe the surroundings, communicate and, to a certain extent, make decisions regarding their tasks [3, 5, 18]. By this, master systems get better information, does not have to deal with downstream organisational issues and increase the transparency of the logistics chain.

Fig. 3 presents a general and futuristic current concept of future information processing in logistics in which the current three-level structure changes into a two-level structure with scattered decision centres. The upper level is for general planning and anticipatory logistics, and uses global information systems, mostly in a cloud environment, while the lower level of the Internet of Things takes operational decisions and controls material flows.

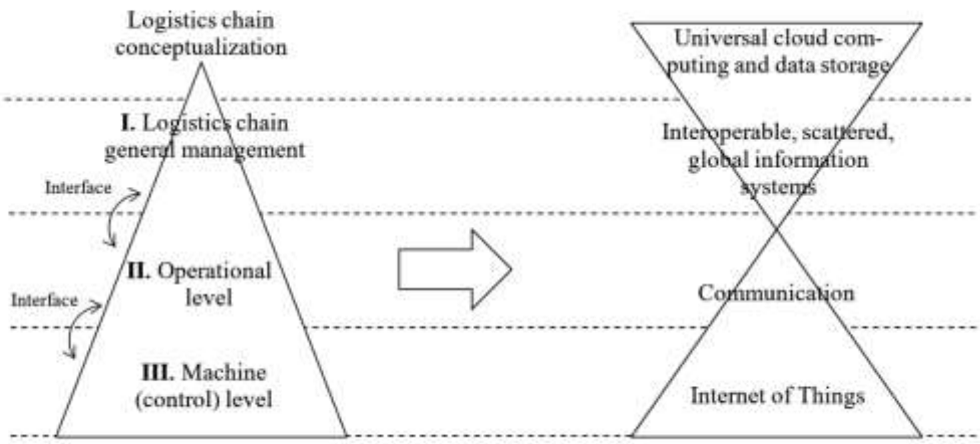

Fig. 3. General concept of future information processing in logistics

This trend is observed in WMS class solutions that work with the warehouse control system (WCS) solutions. Typical WMS is equipped with receive and shipment notification, work order processing, inventory and warehouse locations management, movement logic and performance monitoring. WCS translates orders from WMS to executable commands for material handling systems (MHS) and warehouse automation. Currently, with the increase of sensor capabilities and transfer of computing capabilities to the equipment layer, some WMS functionalities may also be transferred to lower levels. Furthermore, WCS can take movement logic, performance control, and inventory and locations management while elements of movement logic can be moved to the MHS layer. Essentially, WMS stays with core management functions and quality control [22].

The above observation is in line with the general trends described in the next section.

5. DEVELOPMENT TREND IN LOGISTICS INFORMATION SYSTEMS

Computer implementations of logistic information systems and, in general, industry information systems adapt technological achievements in information processing and storage. This is mainly wide access to cheap and miniaturised electronics, efficient data storage and high-resolution radio communication. Similarly, the development of batteries, touchscreens, biometric technologies and photosensitive matrices has resulted in the development of personal devices and wearables, which are the basis of today's AIDC technologies. Automatic identification and data capture (AIDC) is crucial equipment layer communicating warehouse (production) floor with second and first level systems. This layer is also used for internal localisation [21].

High computing capabilities of AIDCs enables transferring simple decision-making to lower level and capturing reliable and rich data directly from the workspace. On the other side of the scale, information systems of the first level absorb further functionalities and change into not only universal but modular cloud-based tools ready to adapt to different logistics systems. These two trends are also visible in other areas of logistics systems.

Fig. 4 presents the logistics information map embracing five crucial fields of information processing in logistics and plausible changes in these fields forced by Logistics 4.0 and IoT coming into effect. Information systems coordinating simple logistics chains will evolve from local, specialised and centralised on-board tools, usually forced to cooperate with similar tools in other links of the supply chain, into interoperable scattered global systems. Now, most of the systems can be classified as modular, multifunctional systems capable of communicating efficiently, like modern ERP or ERP II solutions.

	End of XX. century →			Fully operational Logistics 4.0 and IoT
Information systems in logistics chain	Local, specialized, isolated, centralized tools	Modular, multifunctional tools with local coverage	**Modular multifunctional tools with a global coverage**	Interoperable scattered, global systems
Information systems in logistics facility	Centralization of management and control functions in an insulated tool	**Centralization of management and control functions in a network tool**	Control and control functions at the hardware level, central management	
Databases	Isolated, specialized databases	Isolated, specialized, shared data silos	**Distributed, specialized, shared data sources**	Universal data in scattered, global information systems
Computing power	Central units with universal design	**Central units with a specialized construction**	Cloud resources	Basic cloud computing, scattered calculation units (IoT)
Communication	Exchange of information packages at the central level	**Exchange of information packages in real time at the network level**	Real-time information stream at the central level	Stream of information in real time at all levels

Fig. 4. Logistics information map

Internal information systems in logistics facilities were developed as tools for solving specific local engineering problems, which gradually gained universality. Now, most information systems in logistics facilities centralise management and control functions in a network-based environment; WMSs are examples of such systems. As with systems in the logistics chain, changes related to Logistics 4.0 and IoT will lead to interoperable scattered global systems.

Operation of any information system is dependent on databases and computing power. Industry databases were developed primarily in response to specific industrial demand [10]. Current technological trend assumes universalisation of information, both in content and in format. Standardisation of information will lead to universal databases distributed in global information system (also in cloud), ready for use at all three levels of systems and visible for all participants in logistics network (of course, after overcoming barriers related to reluctance to share information and data secrecy and safety [20, 28]). Computing powers are currently clustered in central industrial units, however, companies understand that better effects can be achieved when computational resources are shared and specialised to specific operations [9, 27]. This leads to cloud resources of computational power and specialised software on the first level of management, and dispersed calculation units installed in things constituting the IoT network.

The last element of logistics information map is communication, which tends to create streams of information transmitted at all levels of information processing systems in real-time to replace exchange of information packages at the network level commonly being used.

5. CONCLUSIONS

Technological changes related to the development of technical civilization (information civilization), most quickly affect those areas of technology, which are to improve comfort and reduce the access time to goods. The new thinking paradigm on information processing is deeply rooted in the business environment and will cause popularisation of technologies of information exchange and use based on scattered acquisition, processing and archiving systems. It will lead to significant changes in the way logistics processes are planned and executed. Significant changes can be expected within a decade and the dominance of distributed information systems within the next 25 years.

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