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SELECTED ASPECTS OF MODELLING RFID SYSTEMS IN SUPPLY CHAINS

Wybrane aspekty modelowania systemów RFID w łańcuchach dostaw

Abstract: *The article presents the technical and organizational assumptions of RFID implementation in selected elements of supply chains, especially in warehouses, transhipment, and terminal facilities. A method of quantifying RFID technology has been proposed. On this basis, the structure of a mathematical model was submitted to evaluate selected performance indicators of RFID solutions in logistics facilities.*
Keywords: RFID, supply chain, modelling

Streszczenie: *W artykule przedstawiono założenia techniczne i organizacyjne wdrażania RFID w wybranych elementach łańcuchów dostaw, szczególnie w obiektach magazynowych, przeładunkowych czy terminalach. Zaproponowano sposób kwantyfikacji technologii RFID. Na tej podstawie zaproponowano strukturę modelu matematycznego do oceny wybranych wskaźników efektywności wdrażania rozwiązań RFID w obiektach logistycznych.*
Słowa kluczowe: RFID, łańcuch dostaw, modelowanie

1. Introduction

The Radio Frequency Identification (RFID) technology offers relatively high reliability and functionality of identification in supply chains compared to bar codes but at a significantly higher price. Since RFID tags can be used repeatedly and do not require visual contact with the reader, in some cases, they turn out to be cheaper than barcodes, as the labour and material consumption are reduced. Then, the benefits of RFID should be considered in the long term and not based on comparing the unit prices of labels and readers.

Modelling the operation of RFID systems in supply chains is a tool to increase the efficiency and reliability of logistics processes, especially in logistics facilities like warehouses, which intensively manipulate units and carry out identification. Although RFID has been used for decades, it still has not become the dominant standard; on the other hand, it still finds new applications in the specific conditions of supply chains.

In supply chains, RFID is associated with warehousing technology and internal transport, including production and commercial service. The main advantages of RFID technology for logistics processes are:

- reduction of labour intensity related to the identification of units at all levels of the packaging hierarchy (reduction of resources, space, and costs),
- cycle counting (compliance between the WMS and the supervisory system),
- support for intelligent solutions in internal transport and tracking the location of resources in space [12] (real-time location systems - RTLS),
- collecting additional information (e.g., temperature control),
- reducing the number of errors,
- increased space utilization resulting from storing and handling compacted units,
- reducing exposure to theft.
- The use of RFID is also associated with potential disadvantages:
- due to the lack of direct eye contact, the system cannot ensure absolute certainty of reading (signal jamming, damaged or missing tags, redundant tags),
- data security issues,
- high cost of labelling (tagging) units, especially for low-value goods,
- problems with reading speed with a large number of tags,
- psychological barrier related to the possible monitoring of staff.

RFID is used in supply chains, but the initial optimism of this technology at the turn of the century has given way to a rational view of the matter. RFID works well where the product is relatively expensive (the price of the tag does not have a large share), material flow is carefully tracked for the order fulfilment, and the final phase of distribution (retail) is labour-consumptive. In other, apart from specialized applications, RFID applications are limited in favour of bar codes.

2. Literature review and problem statement

RFID and its application in supply chains are the research subjects; however, the research topics have not been ultimately used up in this area. Supply chains and logistics networks are subjected to far-reaching changes and modifications under new factors influencing material flows in the global economy. The most visible factors include the COVID-19 pandemic, which resulted in a paradigm shift in the supply chain and the exploration of various technical solutions to increase the reliability and efficiency of supply processes. Other include increasing the volume of material flows, addressing customer needs, and popularizing the Internet of Things in logistics and transport processes.

A complete review of the literature is challenging to perform. Still, it is possible to indicate some trends resulting from the study of new publications in this field.

Biswal, Jenamani, and Kumar [1] studied the RFID application to assess the effect of the available rate of ordering and shrinkage recovery rate on overall costs at the warehouse level. Importantly, they point to the significance of the error, which impacts cost modelling. Szmerekovsky, Tilson and Zhang [21] investigate whether it is possible for the manufacturer as well as the retailer to derive economic benefits from item-level RFID and possible forcing the adoption of RFID by stronger site even if it does not maximize the profit. Tsao, Linh and Lu [24] report on a closed-loop supply chain network for the remanufacturing of products under RFID technology, apply a continuous approximation approach to model the network and show that the adoption of RFID could be highly beneficial. Sari [18] investigate a four-echelon supply chain under different levels of collaboration in a comprehensive simulation model. The results show that benefits are stronger when lead times are longer and/or when demand uncertainty in marketplace is lower. Tao et al. [23] study the RFID adoption strategies in a decentralized supply chain with two competing suppliers and a dominant retailer facing inventory inaccuracies (as in the case of Wallmart, famous [27]). Leung, Cheung and Chu [10] provide an analyse based on six case studies with 88 reported RFID applications to make a clear view of the RFID implementation landscape. They suggest that organizations often mindlessly adopt RFID applications misaligned with their supply chain strategies. Sarac, Absi and Dauzere-Peres [17] or the Raza [16] provide a wide literature review on RFID in supply chains. They point out the simulation methods, case studies, and experiments as effective research methods in this area. Dolgui and Proth [3] also presented state-of-the-art compilation naming the RFID technology of future use. The presence of cross-sectional literature reviews signifies great interest and complexity in the issue of RFID application in supply chains. Dai and Tseng [2], Fan et al. [4] represent the group of authors focusing on inventory management with RFID support and show that it offers a possible solution to alleviate the growing cost of inventory inaccuracy. They present analytical models to quantify the extent of saving from timely information and a reduction in information distortion and its amplification. Vlachos [26] gave an interesting examination of eight RFID applications grouped into two categories: location (different warehouses in the supply chain [20]) and utilization (standards, transportation, pallet level, specialized software) and developed a list of performance indicators. He provided an analytical model placing supply chain performance indicators as dependent variables in a hierarchical regression equation with RFID variables as independent variables. Tan and Sidhu [22] or Lewczuk and Kłodawski [11] address the critical problem of RFID as a component of the Internet of Things (IoT) systems, which is currently becoming the dominant RFID trend in supply chains. They provide a broad literature review in this area.

Most of the analysed works use cost-based performance indicators to assess the effectiveness of RFID solutions, with particular emphasis on ROI (Ustundag, Tanyas [25]). This is in line with commonly used supply chain modelling approaches (e.g. Wasiak et al. [28], Jacyna-Gołda et al. [8, 5, 6]) or approaches based on reliability measures like Semenov and Jacyna [19].

The extensive literature on the subject is based mainly on case studies. However, it is beneficial to build universal analytical tools, such as mathematical models for assessing the effectiveness of RFID implementation in logistics facilities in supply chains. In the following parts of the article, a formal model to evaluate the effectiveness of RFID implementation in a logistics facility was proposed.

3. The conditions of the model

The presented model concerns a logistic facility, such as a warehouse, part of a logistics network. The logistics facility receives deliveries from other facilities in the logistics network and carries out shipments to the next ones. Material flow is quantified into logistic (handling) units according to the packaging hierarchy in the supply chain. The flow of materials through the facility is a sequence of operations (logistic process), ranging from handling means of transport through receipt, storage, replenishment, picking, consolidation and sorting, shipment, and dispatch of vehicles [7, 14]. These transformations are carried out in appropriate areas and locations distinguished physically or functionally in the logistics facility [13]. The flow between areas is a sequence of transport and transformation operations that can be different. Still, in general, they can be reduced to moving, changing the physical form, identifying, controlling, and updating system information, and locating the object (employees and devices) in the space. Units can traverse the logistic facility using different paths [9]. RFID and standard identification technologies can assist passage through the logistics facility, but with different efficiency and reliability.

The structure of a logistics facility is defined as a set of <u>elements</u>: physical sites (locations, sectors, zones, areas, etc.) and the transport links between them. An element of a logistic object services material flow at a certain level of the packaging hierarchy, disposes resources (devices and employees), performs selected functionalities, can have storage (buffering) capacity (if is a physical place), or not (if is a transport connection). The transition of an item between elements is timeless. The elements of the logistics facility can be equipped with RFID solutions at a different implementation level. Labour resources are characterized by efficiency and cost parameters [15]. These parameters will be expressed as execution times of particular types of operations.

The constraints on continuity and the balance of material flow between elements are not considered. The tasks burdening individual elements of the facility are known and that the material flow in a sufficiently long time *T* is balanced. Possible shortcomings are reflected by the probability of an identification error in an element of the logistic object.

A discrete measure can describe the involvement of RFID in the logistics process. RFID technology can be integrated with the logistics process in three dimensions (tab. 1):

1. identification level (type of identified handling units in the packaging hierarchy),
2. functionalities for which RFID is used,
3. fragments (stages) of the warehousing process to be supported by RFID.

Table 1

Integration of RFID with the material flow process in a logistics facility

Level of identification (*w*)		RFID functionalities (*f*)					
		1	2	3	4	5	6
		Vehicle / intermodal unit identification	Identification of handling units	Localization inside the logistics facility	Directed picking / replenishment	Retail support	Site and resource tagging (IoT)
1	Vehicles (bodies) and intermodal transport units	TMS and WMS support in yard management or processes in intermodal terminals	TMS and WMS support in yard management or processes in intermodal terminals	Tracking of containers and bodies in intermodal terminals	Tracking of containers and bodies in intermodal terminals	Not applicable	RTLS, tracing
2	Loading units (e.g. pallets, plastic containers, big-bags)	TMS and WMS support operations	Support for WMS and transaction systems	WMS support in cycle counting and replenishment planning	WMS and WCS support for replenishment	Limited use	RTLS, tracing
3	Multiple packages of various types	TMS and WMS support operations	Support for WMS and transaction systems	WMS support in cycle counting and replenishment planning	WMS and WCS support for replenishment	Limited use	RTLS, tracing
4	Unit packages or pieces	TMS and WMS support operations	Support for WMS and transaction systems	WMS support in cycle counting and replenishment planning	WMS and WCS support for replenishment	Support for sales and commercial process	RTLS, tracing

Table 1 presents a conceptual matrix of RFID integration into a logistics process, especially the warehousing process, which can be used in a mathematical model. The RFID integration is considered a part of the warehouse management system (WMS), warehouse control system (WCS), and transport management system (TMS).

The use of RFID affects the probability of an identification error. Two types of errors are considered:

1. Errors detected while a unit remains in the facility (before being sent to the recipient).
2. Errors identified by the unit recipient in the subsequent objects of the supply chain.

Repairing the effects of the error detected during the process in the facility requires additional work and resources. If the error is not detected, it will generate additional costs in the following parts of the supply chain and influence service reliability. The possibility of an error occurrence can be defined by a random variable and described by a probability distribution correlated to the RFID integration level.

The RFID can be incorporated into various parts of the logistics process and on units of different packaging levels. Additionally, it can support multiple functions in the process (identification, anti-theft, localization) and be based on different technologies with specific features and applications. The mathematical model for evaluating RFID implementation should consider all these factors.

4. Data and variables in the model for assessing the effectiveness of a logistics facility with RFID

To build a model for evaluation of the effectiveness of a logistics facility supported by RFID, the following data have been defined:

- Set of structural elements of the logistic facility: $m \in \boldsymbol{M}$.
- Set of functionalities supported by RFID: $f \in \boldsymbol{F}$ (Tab. 1).
- Set of packaging levels (packaging hierarchy – Tab. 1): $w \in \boldsymbol{W}$.
- Set of variants of RFID technologies: $h \in \boldsymbol{H}$.
- Set of resource types disposed by the logistics facility: $u \in \boldsymbol{U}$.
- Analysis time (facility operation time): T.
- Set of handling units (with different internal packaging structure): $q \in \boldsymbol{Q}$.
- Matrix of handling units packaging structure: $\mathbf{G} = [g(q, w): g(q, w) \in \mathrm{N}^+ \cup \{0\}, q \in \boldsymbol{Q}, w \in \boldsymbol{W}]$, where $g(q, w)$ is a number of items of w packaging level in the unit q.
- Set of technological routes: $s \in \boldsymbol{S}$ (sequences of elements $m \in \boldsymbol{M}$) that handling units pass through the facility, where the set of routes containing the m-th element of a facility is $\boldsymbol{MS}(m)$, and the set of elements making up the route s is $\boldsymbol{M}(s)$.
- Binary matrix assigning functionalities to elements of the logistic facility: $\mathbf{Z} = [z(m, f)]$.

- Matrix of average processing times of handling unit of the packaging level w when the functionality f is implemented by resources u with the use of RFID: **T1** = $[t1(w, f, u)]$, and without the use of RFID: **T2** = $[t1(w, f, u)]$.
- Matrix of the mean error recovery times of the handling unit of the packaging level w when the functionality f is implemented by resource u: **T3** = $[t3(w, f, u)]$.
- Matrix of error probability when handling the unit of the packaging level w when the functionality f is implemented, and RFID of version h is installed: **P1** = $[p1(w, f, h)]$, and without the use of RFID: **P2** = $[p2(w, f)]$.
- Matrix of error detection probabilities when handling the unit of the packaging level w when the functionality f is implemented, and RFID of version h is installed: **P3** = $[p3(w, f, h)]$, and without the use of RFID: **P4** = $[p4(w, f)]$.
- Vector of unit operation costs of resources: **KU** = $[k(u)]$.
- Unit exploitation costs of the RFID system in the h-th technology, with the initial expenditure ER, in time T are described by the function $k1(T, h, ER)$.
- Vector of penalties for handling the unit with an error at the w packaging level by the next link in the supply chain: **K2** = $[k2(w)]$.
- Matrix of time utilization coefficients of resources u applicable when they handle unit of the w packaging level and implement functionality f: **ΦU** = $[\varphi(u, w, f)]$.
- Matrix of material flow pile-up coefficients in the element m implementing functionality f: **Γ** = $[\gamma(m, f): \gamma(m, f) \in R^+ \wedge \gamma(m, f) \geq 1]$.
- Matrix of unit expenditure on marking (labelling) units of the packaging level w in the h-th version of the RFID system (purchase of tags): **EW** = $[e(w, h)]$.
- Matrix of unit expenditure on equipping resources u with RFID components of the h-th version: **EU** = $[e(u, h)]$.
- Matrix of unit expenditure on equipping the space of the element m with RFID components of the h-th version depending on the functionality f: **EM** = $[e(m, h, f)]$.

The model may aim to optimize or assess the implementation of RFID in a logistics facility. Therefore, decision variables are not formulated if it is assumed that variables can be of a certain value and become a constant:

- $x1(m, w)$ – binary variable, $x1(m, w) = 1$, if the element m of the logistics facility handles units of w packaging level, where $\forall m \in \boldsymbol{M}\ \sum_{w \in \boldsymbol{W}} x1(w, m) = 1$.
- $x2(m, u)$ – binary variable, $x2(m, u) = 1$, if the element m of the logistics facility uses resources u, where $\forall m \in \boldsymbol{M}\ \sum_{u \in \boldsymbol{U}} x2(u, m) = 1$.
- $x4(h)$ – binary variable, $x4(h) = 1$, if the h-th version of RFID technology is implemented in the logistics facility, where $\sum_{h \in \boldsymbol{H}} x4(h) = 1$.
- $x5(m, f)$ – binary variable, $x5(m, f) = 1$, if the element m of the logistics facility provides functionality f, where $\forall m \in \boldsymbol{M}\ \sum_{f \in \boldsymbol{F}} x5(m, f) \geq 1$.
- $x6(q, s)$ – binary variable, $x6(q, s) = 1$, when the handling unit q flows through the logistics facility on the route s, where $\forall q \in \boldsymbol{Q}\ \sum_{s \in \boldsymbol{S}} x6(q, s) = 1$.

5. The key technological parameters of a logistics facility and logistics processes with RFID

The data and variables formulated in Chapter 4 allow for including the basic features of a logistics facility with RFID implemented:

- The number of identification errors made in the handling units of the *w* packaging level during service in the element *m* of the logistic object:

$$\forall m \in \boldsymbol{M}\ \forall w \in \boldsymbol{W} \quad Bz(m,w) = \sum_{q\in \boldsymbol{Q}} \sum_{s\in \boldsymbol{MS}(m)} \sum_{f\in \boldsymbol{F}} \sum_{h\in \boldsymbol{H}} x6(q,s)\cdot x1(m,w)\cdot z(m,f)\cdot g(q,w)\cdot \Big(x5(m,f)\cdot p1(w,f,h)\cdot x4(h) + \big(1-x5(m,f)\big)\cdot p2(w,f)\Big) \tag{1}$$

- The number of identification errors detected in the handling units of the *w* packaging level during service in the element *m* of the logistic object:

$$\forall m \in \boldsymbol{M}\ \forall w \in \boldsymbol{W} \quad Bw(m,w) = \sum_{q\in \boldsymbol{Q}} \sum_{s\in \boldsymbol{MS}(m)} \sum_{f\in \boldsymbol{F}} \sum_{h\in \boldsymbol{H}} x6(q,s)\cdot x1(m,w)\cdot z(m,f)\cdot g(q,w)\cdot \Big(x5(m,f)\cdot p3(w,f,h)\cdot x4(h) + \big(1-x5(m,f)\big)\cdot p4(w,f)\Big) \tag{2}$$

- The number of identification errors in the handling units of the *w* packaging level shipped from the logistic facility:

$$\forall w \in \boldsymbol{W} \quad B(w) = \sum_{m\in \boldsymbol{M}} \big(Bz(m,w) - Bw(m,w)\big) \tag{3}$$

- The labour intensity of the resource *u* performing the logistics process in the element *m* of the logistics facility:

$$\forall m \in \boldsymbol{M}\ \forall u \in \boldsymbol{U}$$

$$L(m,u) = \sum_{q\in \boldsymbol{Q}} \sum_{s\in \boldsymbol{MS}(m)} \sum_{f\in \boldsymbol{F}} \sum_{w\in \boldsymbol{W}} \sum_{c\in \boldsymbol{C}} x6(q,s)\cdot x1(m,w)\cdot x2(m,u)\cdot z(m,f)\cdot g(q,w) \cdot \gamma(m,f)\cdot \Big(x5(m,f)\cdot t1(w,f,u) + \big(1-x5(m,f)\big)\cdot t2(w,f,u)\Big) + Bw(m,w)\cdot t3(w,f,u) \tag{4}$$

The benefits (or losses) of RFID have a technical dimension that can be expressed with economic measures, and thus the efficiency of the logistics facility and supply chain:

- The costs of work of resources *u* over time *T*:

$$\forall u \in \boldsymbol{U} \quad K(u) = \left\lceil \frac{\sum_{m\in \boldsymbol{M}} L(m,u)}{T\cdot \varphi(u,w,f)} \right\rceil \cdot T\cdot k(u) \tag{5}$$

- Number of tags (RFID labels) of the *w* packaging level of the *h*-th version of the RFID system used in the logistics facility over time *T*:

$$\forall w \in \boldsymbol{W}\ \forall h \in \boldsymbol{H}$$

$$nt(w,h) = \sum_{q \in \boldsymbol{Q}} \max_{s \in \boldsymbol{S}, m \in \boldsymbol{M}(s), h \in \boldsymbol{H}} \{x6(q,s) \cdot x1(m,w) \cdot g(q,w) \cdot x4(h)\} \tag{6}$$

- Investment expenditures on equipping resources with mobile RFID devices in the *h*-th version of the system:

$$\forall h \in \boldsymbol{H} \quad Eu(h) = x4(h) \cdot \sum_{c \in \boldsymbol{C}} n(u) \cdot e(u,h) \tag{7}$$

- Investment expenditures on equipping space with stationary RFID devices in the *h*-th version of the system:

$$\forall h \in \boldsymbol{H} \quad Ep(h) = x4(h) \cdot \sum_{m \in \boldsymbol{M}} \sum_{f \in \boldsymbol{F}} x5(m,f) \cdot e(m,h,f) \tag{8}$$

- Total expenditure on RFID implementation in a logistics facility:

$$ER(T) = \sum_{h \in \boldsymbol{H}} \big(Eu(h) + Ep(h) + EIt(h)\big) \tag{9}$$

- The cost of purchasing tags in the *h*-th version of the RFID system used in the logistics facility over time *T*:

$$\forall h \in \boldsymbol{H} \quad Kt(h,T) = \sum_{w \in \boldsymbol{W}} nt(w,h) \cdot e(w,h) \tag{10}$$

- The cost of maintaining the *h*-th version of the RFID system in the logistics facility over time *T*:

$$\forall h \in \boldsymbol{H} \quad Kr(h,T) = Kt(h,T) + k1\big(T,h,ER(T)\big) \tag{11}$$

- Total cost of maintaining an RFID system at a logistics facility over time *T*:

$$Kr(T) = \sum_{h \in \boldsymbol{H}} Kr(h,T) \tag{12}$$

- Error handling costs further down the supply chain (after units are shipped from the logistics facility) over time *T*:

$$Kb(T) = \sum_{w \in \boldsymbol{W}} B(w) \cdot k2(w) \tag{13}$$

- Total costs over time *T*:

$$K(T) = Kr(T) + Kb(T) \tag{14}$$

Based on these characteristics, it is possible to formulate efficiency measures based on costs, inputs, and efficiency for a logistics facility. After extending the model, it is also the supply chain in which it is located.

6. Conclusions and further actions

The presented model for assessing the implementation of RFID technology in a logistics facility can evaluate the efficiency of the whole supply chain, assuming that the inputs and outputs of all elements will be synchronized, and the transport factor will be taken into account. This model can be used to analyse parts of the logistics process and the entire process in the supply chain due to its scalability and modularity resulting from the construction principles of the logistics facility element, which may reflect various places and tasks in the logistics process and assigned resources.

An important element of using the model is formulating time and probabilistic data based on implementation or simulation studies.

The next step in the implementation of research works is developing a simulation model that will allow the use of the proposed mathematical model to assess the effectiveness of RFID implementation in logistics facilities. The model will be implemented as a critical component of the simulation tool, which in the first stage will evaluate the implementation of RFID in a logistics facility by reflecting the structure of the logistics facility following the assumptions of the mathematical model and using data structures obtained through measurements and experiments. In the second stage, sets of logistics facilities will be combined into the structures of supply chains and assessed globally.

7. References

1. Biswal A. K., Jenamani M., Kumar S. K.: Warehouse efficiency improvement using RFID in a humanitarian supply chain: Implications for Indian food security system. Transp. Res. Part E 109 (2018) 205–224. https://doi.org/10.1016/j.tre.2017.11.010.
2. Dai H., Tseng M. M.: The impacts of RFID implementation on reducing inventory inaccuracy in a multi-stage supply chain. Int. J. Production Economics 139 (2012) 634–641. http://dx.doi.org/10.1016/j.ijpe.2012.06.005.

3. Dolgui A., Proth J. A.: RFID technology in supply chain management: state of the art and perspectives. Proceedings of the 17th World Congress The International Federation of Automatic Control Seoul, Korea, July 6-11, 2008. 10.3182/20080706-5-KR-1001.1399.
4. Fan T., Tao F., Deng S., Li S.: Impact of RFID technology on supply chain decisions with inventory inaccuracies. Int. J. Production Economics 159(2015), 117–125. http://dx.doi.org/10.1016/j.ijpe.2014.10.004.
5. Jacyna-Gołda I. Decision-making model for supporting supply chain efficiency evaluation. The Archives of Transport, 33(1), 2015, 10.5604/08669546.1160923 17.
6. Jacyna-Gołda I., Izdebski M., Szczepański E., Gołda P. The assessment of supply chain effectiveness. The Archives of Transport, 45(1), 2018, 10.5604/01.3001.0012.0966.
7. Jacyna-Gołda I., Kłodawski M., Lewczuk K., Łajszczak M., Chojnacki T., Siedlecka-Wójcikowska T.: Elements of perfect order rate research in logistics chains, Archives of Transport, 49(1), 2019, s. 25-35, 10.5604/01.3001.0013.2771.
8. Jacyna-Gołda I., Wasiak M., Izdebski M. [i in.]: The evaluation of the efficiency of supply chain configuration, in: 20th International Conference Transport Means 2016. Proceedings / Kersys Robertas (ed.), TRANSPORT MEANS, 2016, Kowno, Publishing House "Technologija", s. 953-957, ISBN 1822-296X.
9. Kłodawski M., Lewczuk K., Jacyna-Gołda I., Żak J.: Decision making strategies for warehouse operations. Archives of Transport, 41(1), 2017, s. 43-53, 10.5604/01.3001.0009.7384.
10. Leung J., Cheung W., Chu S. C.: Aligning RFID applications with supply chain strategies. Information & Management, 51 (2014) 260–269. 10.1016/j.im. 2013.11.010.
11. Lewczuk K., Kłodawski M.: Logistics information processing systems on the threshold of IoT, Zeszyty Naukowe. Transport - Politechnika Śląska, Politechnika Śląska, vol. 107, 2020, DOI:10.20858/sjsutst.2020.107.6.
12. Lewczuk K., Załęski A.: Selected aspects of indoor positioning based on AIDC elements in warehouse facilities, Journal of KONES, vol. 25, nr 4, 2018, s. 555-562, DOI:10.5604/01.3001.0012.8005.
13. Lewczuk K.: Dependability issues in designing warehouse facilities and their functional areas, Journal of KONBiN, vol. 2, iss. 38, 2016, s. 201-228, DOI:10.1515/jok-2016-0024.
14. Lewczuk K.: Modelowanie procesów w systemach magazynowych w zastosowaniu do oceny niezawodności i efektywności ich funkcjonowania, 2016, Oficyna Wydawnicza Politechniki Warszawskiej, ISBN 978-83-7814-638-4, 130 s.
15. Pyza D., Jachimowski R., Jacyna-Gołda I., Lewczuk K.: Performance of Equipment and Means of Internal Transport and Efficiency of Implementation of Warehouse Processes. 10th International Scientific Conference on Transportation Science and Technology TRANSBALTICA 2017: Transportation science and technology 187, pp. 706-711.

16. Raza S. A.: A systematic literature review of RFID in supply chain management. Journal of Enterprise Information Management. Vol. 35 No. 2, 2022, pp. 617-649. DOI 10.1108/JEIM-08-2020-0322.
17. Sarac A., Absi N., Dauzere-Peres S.: A literature review on the impact of RFID technologies on supply chain management. Int. J. Production Economics 128 (2010): 77–95. 10.1016/j.ijpe.2010.07.039.
18. Sari K.: Exploring the impacts of radio frequency identification (RFID) technology on supply chain performance. European Journal of Operational Research 207 (2010) 174–183. 10.1016/j.ejor.2010.04.003.
19. Semenov I., Jacyna M.: The synthesis model as a planning tool for effective supply chains resistant to adverse events, Eksploatacja i Niezawodność, Polskie Naukowo-Techniczne Towarzystwo Eksploatacyjne, vol. 24, nr 1, 2022, s. 140-152, DOI:10.17531/ein.2022.1.16.
20. Szczepański E., Jachimowski R., Izdebski M., Jacyna-Gołda I. Warehouse location problem in supply chain designing: a simulation analysis. The Archives of Transport. Vol. 50, Iss. 2, 2019. DOI: 10.5604/01.3001.0013.5752.
21. Szmerekovsky J. G., Tilson V., Zhang J.: Analytical model of adoption of item level RFID in a two-echelon supply chain with shelf-space and price-dependent demand. Decision Support Systems 51 (2011) 833–841. 10.1016/j.dss.2011.02.002.
22. Tan W. C., Sidhu M. S.: Review of RFID and IoT integration in supply chain management. Operations Research Perspectives 9 (2022) 100229. https://doi.org/10.1016/j.orp.2022.100229.
23. Tao F., Wang L., Fan T., Yu H.: RFID adoption strategy in a retailer-dominant supply chain with competing suppliers. European Journal of Operational Research (early access Jan 2022). https://doi.org/10.1016/j.ejor.2021.12.008.
24. Tsao Y. C., Linh V. T., Lu J. C.: Closed-loop supply chain network designs considering RFID adoption. Computers & Industrial Engineering 113 (2017) 716-726. 10.1016/j.cie.2016.09.016.
25. Ustundag A., Tanyas M.: The impacts of Radio Frequency Identification (RFID) technology on supply chain costs. Transportation Research Part E 45 (2009) 29–38. 10.1016/j.tre.2008.09.001.
26. Vlachos I. P.: A hierarchical model of the impact of RFID practices on retail supply chain performance. Expert Systems with Applications 41 (2014) 5–15. 10.1016/j.eswa.2013.07.006.
27. Wallmart webstie: https://www.rfidjournal.com/walmart-re-commits-to-rfid-with-supplier-mandates (access 02.02.2022).
28. Wasiak M, Jacyna-Gołda I, Markowska K, Jachimowski R, Kłodawski M, Izdebski M. The use of a supply chain configuration model to assess the reliability of logistics processes. Eksploatacja i Niezawodność – Maintenance and Reliability 2019; 21 (3): 367–374. 10.17531/ein.2019.3.2.