Yet Another Warehouse KPI's Collection

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Abstract: Warehouses are strategic systems for all supply chains since their performances impact operations and efficiency of all direct and indirect stakeholders. Therefore, monitoring warehouses' performances constantly and real-time is getting so important, both to guarantee an effective warehouse management and to detect in advance anomalous and potentially destructive trends. The current literature about warehousing Key Performance Indicators (KPI) appears to lack an extensive collection. Classification logics are often partial or based on specific contexts. At the same time, the amount and typology of data collected on the warehouse often hinder a consistent performance monitoring. This paper aims to fill such gap and guide organizations in identifying the relevant information to gather for warehouse performance monitoring. Firstly, a scoping literature review was conducted to provide an extensive list of warehouse KPIs. Then, the collected results set the groundwork for a dynamic and interactive database called YAWKC. This tool is designed as a knowledge graph allowing for non-linear exploration of data and for continuous enrichment by experts' contribution, representing the starting point for further knowledge generation in an explorable, dynamic and potentially ever-growing way.

Keywords: Knowledge Management, Zettelkasten, Business Intelligence, Obsidian

I. MOTIVATION

Some authors underline the impact of business intelligence practice on warehouse management [1–3]; others, considering that there is no single approach valid for all contexts, propose general conceptual frameworks for KPI development [4–6]. The novice however has necessity to start from an initial set of KPIs used in the actual practice. Unfortunately, the literature on the subject is fragmentary. Sometimes, the proposed KPIs collections are generic or mainly focused to single use cases. Most of them fail to provide an extensive list of indicators consolidated by their actual use in the daily practice.

Recognizing the importance of knowledge management in business, here an alternative solution to a typical existing literature review has been proposed for the two following reasons: the literature review, although fundamental in its importance, inevitably remains a tool relegated to the Academy, difficult to use as well as poorly accessible by professionals; secondly, an article remains crystallized at the time of its publication, immutable and, therefore, destined to be replaced by newer publications – as is normal and desirable in scientific progress. In contrast, knowledge management requires a persistent but modifiable medium so that old information can be supplemented with more current data. Moreover, such support must be relatively easy to query. Hopefully, it must also be user-friendly, guiding the user through preferential interpretive paths. Such a tool resembles something other than an article, much more closer to a database. This article presents a collection of warehouse indicators interactively explorable as a database called "Yet Another Warehouse KPI's Collection" (YAWKC), intended as an easy to use tool for everyone involved in warehouse Management, whether is student, teacher, or professional. To achieve such project were scrutinized three personal knowledge management applications: Zettlr [7], Obsidian [8], and Notion [9]. All t rely on Markdown, a popular mark-up language that allows for expressive richness in formatting texts. The final choice fell on Obsidian, since it also presents relationships between documents as a graph.

The remainder of the article is structured as follows: Section II recaps some relevant reviews used as benchmark collections of KPIs. Section III describes both the overall research and the building of YAWKC processes, as well as it introduces Obsidian, the main software used in this project. Section IV highlights major results, while section V explains how to use YAWKC. Lastly, section VI highlights the limitation of this research and draws some conclusions, exploring also possible other application of both YAWKC and its building process.

II. RELEVANT REVIEWS ON WAREHOUSE KPIS

For the sake of truth, YAWKC started as a spinoff from a larger research project that required collecting as many warehouse indicators as possible. As devoted scholars to Operations Management and Logistics do-

mains, we already knew some relevant works on measurement of warehouses' performance. Particularly renowned in debating indicators is the book "World-class warehousing and material handling" [10]. In that book, Frazelle distinguishes logically the functional areas of a generic warehouse and, accordingly, he lists KPIs for the *Receiving and Unloading*, *Put away and Storage*, *Order Picking*, and *Shipping* areas. That book, even though still considered a milestone, begins to suffer the burden of the years, indeed its original classification dates back to the year 2002.

We identified four relevant other more recent works collecting warehousing KPIs. The first study provides framework for classification of performance indicators according to time, cost, quality and productivity dimensions [11]; the second one focuses on warehousing industry in Malaysia in 2018 [12]. The authors, by using Analytical Hierarchy Process, provides a ranking of indicators to measure the warehouse productivity and to make recommendations for future policies. In the third article the classification provided by [11] has been followed to refine a set of KPIs for benchmarking warehouse performance globally [13]. Faveto et al. in 2021 proposed a novel approach to define a comprehensive evaluation framework for warehouse management systems, by taking a holistic view on WMS and by considering KPIs that have been used in scientific research [5]. These articles were particularly relevant to the development of YAWKC and therefore they were used as a benchmark in this research.

III. METHODS

A. *The overarching process followed in this research*

As reported in the previous section, the YAWKC project arose after the need of collecting as KPIs as much as possible. The first impulse has been to look into a distinguished database for being fully peer-reviewed compliant e.g. Scopus.

The query **(TITLE-ABS-KEY (warehouse OR warehouses) AND TITLE-ABS-KEY((index OR indices OR indicator OR indicators OR kpi OR kpis) AND (table OR list))) AND (LIMIT-TO (DOCTYPE , "re"))** looked for review documents having *index* or *KPIs* and *warehouse* in the title, abstract, or keywords; unfortunately, this first query reported only two irrelevant results. A second query: **(TITLE-ABS-KEY (warehouse OR warehouses) AND TITLE-ABS-KEY (index OR indices OR indicator OR indicators OR kpi OR kpis AND table OR list) AND NOT TITLE-ABS-KEY (data W/3 warehouse))** looked for any kind of articles with the only requisite of excluding the copresence of the word *data* and *warehouse* within three words.

This has been done to exclude documents concerning data-warehouse topics. The latter search returned 32 documents, yet one of them was the already known work of Faveto [5]; the remaining 31 were irrelevant. This preliminary research conducted on Scopus corresponds to the stage (a) depicted in Fig. 1.

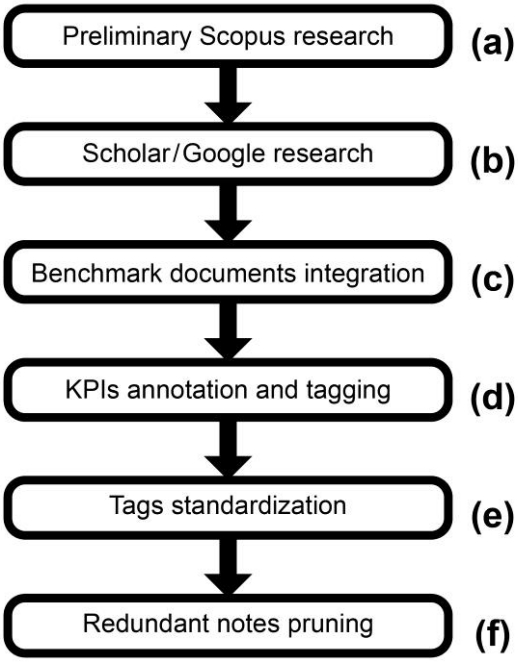

Fig. 1. The entire research process

(b): In light of the realization that the goal was not to have a systematic literature review of the KPIs used in warehouses, rather only to collect as many indicators as possible, it was decided to search for papers outside of Scopus, foregoing from the outset performing more in-depth analyses of Scopus or other peer-reviewed databases. Warehouse. **AROUND (4) (KPI OR KPIs) (Index OR indices) AROUND(3) warehouse filetype: pdf** was the query performed over Scholar and Google search engines. In particular, here the choice of the sources fell on master's theses. These types of documents are generally based on textbooks, scientific articles, and real application cases, although they would not be considered completely reliable texts, since they have not undergone standard peer review. However, for the purposes of this project, these documents could be added without any particular impediment. Of course, these documents are also referenced. This increased the total number of documents considered to 44.

(c): The already known documents (cited in the section II ([10-13] and [5]) have been integrated in the kpis gathering. Moreover the have been also used as benchmark to assess the value of YAWKC in comparison. The remaining stages (d-f) of the process followed in this research required the introduction of some concepts specific for Obsidian, the software used to build YAWKC, therefore their explanation is postponed to subsection *C.*

B. *Introducing Obsidian software*

The Zettelkasten (slip-box) method is a research methodology, perfectioned during his career, by the extreme-

ly prolific author (more than 70 books and 400 scientific articles published) Niklas Luhmann to keep track of every information acquired during lectures, reading, conferences, or any other academic activity. Starting from the consideration that a single idea is only valuable as its context, but not necessarily this latter must be the same the idea was taken from, Luhmann thought about the same idea might relate and therefore contribute to different contexts. With his method, Luhmann embraced the non-linearity of the research process and tried to emulate the human association of ideas process method. The entire Zettelkasten can be seen as a physical implementation of a hypertext. Obsidian is a note-taking application that implements Zettelkasten, by expanding it with many other interesting features, like the possibility of performing advance search queries and representing visually the links between the notes. Obsidian is both a note-taking app, a personal knowledge management system, and a database. Although, the advantages in the scientific research and writing process are quite obvious, it is a tool that has not yet become part of the arsenal of academics. As authors, we believe that its potential has not yet been fully explored, and the present educational project is to be understood in that sense.

A generic project in Obsidian is called a *vault* and it consists of a folder containing several text files with .md extension (Markdown files). These files can be further organized in subfolders that will appear in the application outline side pane. Each of these .md file – namely a *note* – gains power especially when is linked to other notes, akin to atomic thoughts forming a connected reasoning chain. A direct link (i.e., hard link) is made by enclosing the name of another note by a double couple of square brackets. Another kind of link (a weak one) can be created by tagging. Two notes sharing the same tag (i.e., the # character followed by a word) are seen as clustered by the application. Tagging, in Obsidian, is often used as way to let the thoughts' association emerge. Indeed, clustered notes might subsume some latent topics, and this can be used to build sense making starting from apparently uncorrelated atomic notes, as in [14]. Throughout the whole application's interface, information can be retrieved in several different ways: by using queries, tags, links, and even by selecting randomly a note. All these features, along with the ability to represent a vault as a knowledge graph, make Obsidian a ready-to-use tool for knowledge management of small/medium-size projects.

C. The YAWKC building process

Now that the terminology has been clarified, it is possible to continue describing the process followed to build YAWKC. After the (c) stage, at least one indicator or measure related to warehousing was extracted from each of the included documents.

(d): Any extracted KPI has been assigned to a note reporting its definition and, whenever available, its analytical formula, by leveraging the formatting capabilities of Markdown language (Fig. 2).

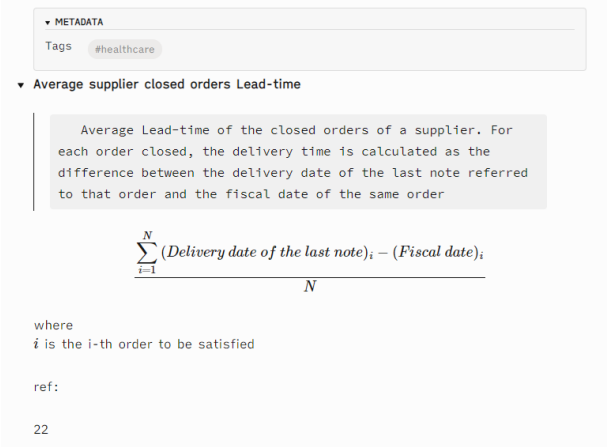

Fig. 2. The KPI "Average supplier closed orders Lead-time" note; description, formula, and reference (e.g., 22) fields are evident

At the same time, to any note have been assigned several tags (semantically related to the document from which the KPI had been extracted e.g., if the document described warehouse for food distribution the tag #food was associated). Whenever an alternative nomenclature was found, this has been annotated also as an alias (i.e., alternative name) in the same note. At the end of stage (d) 121 indicators were collected

(e): Following a similar approach used in [14], three researchers collected and uniformed all the used tags to make sense of the different KPIs. Specifically, the research team identified the taxonomy proposed by Frazelle [10] as a sufficiently satisfactory way to present KPIs for both teaching and work practice. As highlighted in section II, such taxonomy classifies KPIs accordingly to the functional areas belonging to a typical warehouse, namely: Receiving and Unloading; Put Away and Storage; Order Picking; Shipping (see Table I).

TABLE I
NUMBER OF KPIS ACCORDING TO FRAZELLE'S TAXONOMY

Category	Number of KPIs
Receiving and Unloading	**21**
Put Away and Storage	**34**
Order Picking	**37**
Shipping	**23**

Additional notes were created for each of Frazelle's category. These "higher level" notes (*permanent*, see [14]) serve the purpose of guiding the user through YAWKC by following Frazelle's path of interpretation. Once such notes with all the hard links to the relative KPIs were put in place, the corresponding Frazelle's category tags become redundant and, therefore, were deleted.

Moreover, many tags were recognized as uninformative, because ascribed either to too few or to too many KPIs. They were deleted as well. After that pruning stage the

remaining tags were normalized (i.e., semantically equivalent tags such as #food, #food_and_beverages, #meat, #vegatables, # dairy were all merged into #food_and_beverage). Some tags represented existing logical categories (*Administration, Cost, Manpower, Quality, Safety, Time, Direct Measures*), although outside the Frazelle taxonomy, so it was decided to create new high-level notes to collect them. Similar to the Frazelle categories, once the tags to the notes were replaced with hard links the corresponding tags were deleted. Table II reports the number of the KPIs identified in such newer categorization.

TABLE II
NUMBER OF KPIS NOT INCLUDED IN FRAZELLE'S TAXONOMY

Category	Number of KPIs
Administration	**7**
Costs	**20**
Direct Measures	**16**
Manpower	**8**
Quality	**6**
Safety	**8**
Time	**17**

The new categories identified are: *Administration*, regarding KPIs potentially relevant for the administrative office; *Costs*, which lists every indicator measuring direct or indirect costs; *Manpower*, which takes in account measures concerning operators performances (e.g., "Pick rate per operator"; "Order lines picked per manhour"; "Employee Turnover Rate", etc.); *Quality*, listing any kind of KPIs regarding quality issues (e.g., "Cargo damage rate", "Customer satisfaction", "% Receipts processed accurately", etc.); *Safety*, which includes indicators such as "Accidents per year", "Fire load", and "Time lost due to injury".

Two peculiar categories identified are *Time* and *Direct Measures*; the former including any time-related KPIs (e.g., Average Delivery Delay; Notification-to-refund time; Time lost due to injury", etc.); the latter listing all the direct measurements that are used as a basis to build other more complex KPIs.

TABLE III
NUMBER OF KPIS RELATED TO THE REMAINING TAGS

Tag	Number of KPIs
#logistics	**33**
#food_and_beverage	**29**
#healthcare	**13**
#oil_and_gas	**11**

The remaining tags were not deemed to merit a specific categorization since they were assigned only in consideration of the particular case study reported in the original document from which the KPI was originally extracted (Table III).

(f): In this stage all the aliases and tags were verified to further prune the overlapping notes. Currently, in YAWKC are contained 109 distinct KPIs (i.e., notes), meaning that when any alternative nomenclature exists is reported as an alias.

After this final stage, an index note (the interested reader can find more information in [14]) called *Start here* was added (Fig. 3). Such note provides instructions and ready to use interpretative pathways for the user. Section V details the usage of YAWKC.

IV. RESULTS

The intentions that YAWKC be a persistent, expandable and explorable information object, and that it contain as many KPIs as possible, were deemed to be prioritized over achieving a systematic review of the relevant literature. Especially given the current difficulty of equipping oneself with a substantial number of indicators resting solely on the Scopus database, there is no doubt that YAWKC represents a consistent and accessible source of information for those who need access to a collection of warehouse indicators. This is confirmed by the huge number of indicators collected as can be seen in table IV

TABLE IV
NUMBER OF UNIQUE KPIS INCLUDED IN YAWKC COMPARED TO THOSE BELONGING TO BENCHMARK REVIEWS OF LITERATURE

Reference	Year	Number of included KPIs
[10]	**2002**	**25**
[11]	**2015**	**38**
[12]	**2018**	**10**
[13]	**2021**	**11**
[5]	**2021**	**70**
YAWKC	**2022**	**109**

V. HOW TO USE THE YAWKC

To use YAWKC the user must have previously installed the software Obsidian, in addition She or He must also have the *YAWKC_Obsidian_Vault* folder downloaded from the link provided in the acknowledgments section of the present article.

It will be sufficient to run the *open folder as vault* command pointing to the *YAWKC_Obsidian_Vault* to launch the tool. On the left pane the user can see all the existing notes among which will have to select the note called *Start here*. Such index note would help the user to an easy usage of YAWKC. The note offers five initial

suggested exploration path derived from Frazelle taxonomy. Otherwise the users can chose one of the categories outside Frazelle taxonomy. The Fig. 3 depicts the Start here note.

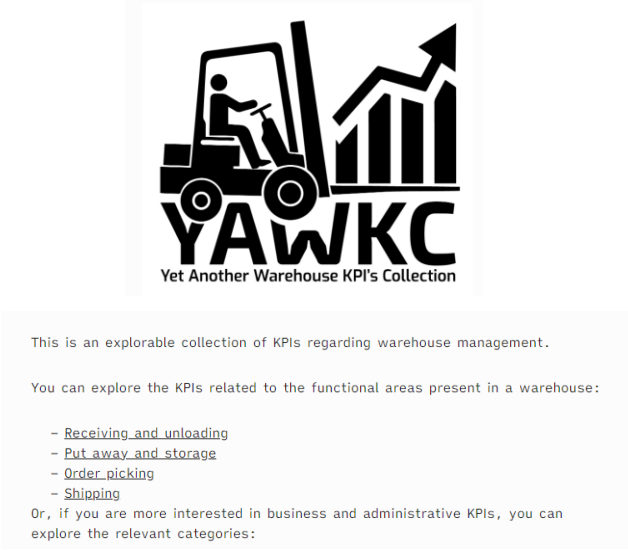

Fig. 3. The *Start here* index note.

As an alternative usage mode, users can explore directly the knowledge graph (Fig. 4)

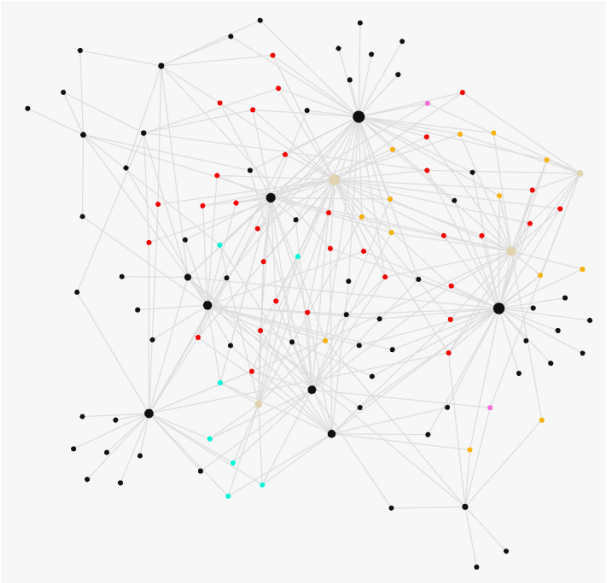

Fig. 4. The YAWKC knowledge graph. Dots are colored according to the main tags in the corresponding KPI (see Fig. 5

Each dot in the graph represents a note. The little ones are KPIs' notes which gather around some bigger grey dots. These latter are the suggested interpretative categories (higher level notes) from which the corresponding direct (hard) links depart. The tags (weak kinks) remaining after the pruning process described in section III form four different clusters, therefore it was convenient to highlight them with a specific color always visible (Fig. 5).

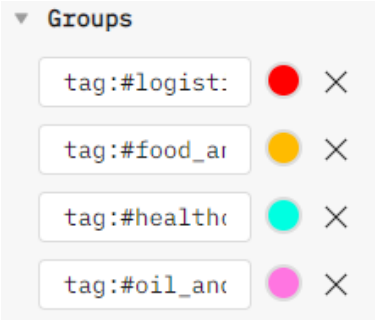

Fig. 5. The tags that have remained after the process described in section III are used to assign colors to the corresponding groups of notes.

Hovering over a KPI node will display the name of the corresponding KPI and the categories whose it belongs to (Fig. 6).

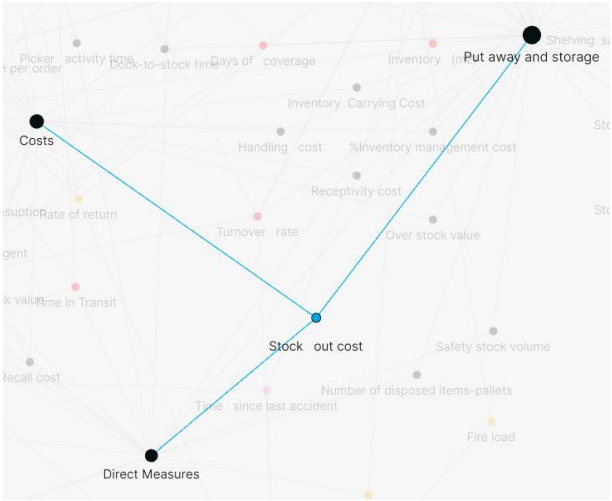

Fig. 6. A detail of the Stock out cost KPI which belongs at the same time to the categories *Costs*, *Direct Measures*, and *Put away and storage* .

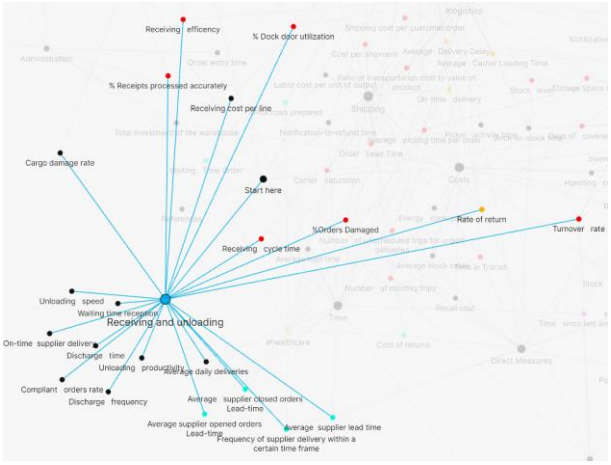

Fig. 7. A detail of the Receiving and unloading category with the linked KPIs.

In a similar fashion, hovering over a category node (i.e., one of the grey big dots) will display the name of the corresponding category and at the same time its links to the related KPIs (Fig. 7). Differently, when the user

click on a node, the selected note will open showing the corresponding KPI (see Fig. 2 in section III).

VI. Conclusions

This article presented the YAWKC collection: 109 warehouse management KPIs freely consultable both for professional and educational purposes, in an interactive and visual manner, by leveraging the features of the Obsidian software application. The tool provides eleven different categories possibly useful to interpret the indicators: four follow the functional logic of a warehouse typical areas introduced with the Frazelle's taxonomy. The remaining seven move away from the Frazelle's taxonomy and include categories relevant for managers (e.g., *Administration, Costs, Manpower, Quality, Safety, Time*) or fundamental essential to build other KPIs (e.g., *Direct Measures*).

The 109 KPIs included in YAWKC have been collected mainly from master theses, which are documents usually not subjected to a formal peer review process. However, YAWKC has been compared with other 5 selected benchmark reviews collecting KPIs used in warehousing, and YAWKC ranks first in terms of indicators included. At present time, YAWKC can be inspected with any Markdown interpreter or, failing that, any text editor. However, YAWKC was designed to be an Obsidian vault, so it is by opening it with this software that it expresses its full potential, enabling its interactive and visual navigation, and allowing for real-time transferability, expandability and modifiability of KPIs, whilst remaining embedded in a persistent information object.

YAWKC suffers from some limitations, such as the need to learn how to use Obsidian and, far more serious, the fact that it mostly rests on master theses which are usually not subject to formal review.

However, as a starting point for implementing dashboards or other business intelligence tool, YAWKC can be extremely valuable. Moreover, it might be used as an important educational support tool.

As authors we want to emphasize that the value of YAWKC will increase as we read more articles and incur new KPI definitions, because the potential links between them will also increase correspondingly. Indeed, like any formalized knowledge base, knowledge graphs become more relevant the more they grow in size. Not to mention that the construction process used for YAWKC can be replicated to concepts other than indicators and, in each case, the result can be linked to YAWKC, potentially forming a broader and more comprehensive knowledge base on warehouses. In principle, there is no limit to the replicability and expandability of the process, consequently, it is possible to merge vaults belonging to different application domains to identify commonalities and differences. All in all, YAWKC is a valuable aid in the study and practice of operations management.

Acknowledgments

YAWKC is freely downloadable from the link:

https://drive.google.com/drive/folders/1mB8mNfNpHnNW52l0mDMRIlegnAfCzIYq?usp=sharing

To explore YAWKC you must have previously installed Obsidian on your computer.

References

[1] Nuseir, M.T. Designing business intelligence (BI) for production, distribution and customer services: a case study of a UAE-based organization. Bus. Process Manag. J. 2020, 27, 1275–1295, doi:10.1108/BPMJ-06-2020-0266.

[2] Kusrini, E.; Novendri, F.; Helia, V.N. Determining key performance indicators for warehouse performance measurement - A case study in construction materials warehouse. In Proceedings of the MATEC Web of Conferences; 2018; Vol. 154.

[3] Torabizadeh, M.; Yusof, N.M.; Ma'aram, A.; Shaharoun, A.M. Identifying sustainable warehouse management system indicators and proposing new weighting method. J. Clean. Prod. 2020, 248, doi:10.1016/j.jclepro.2019.119190.

[4] Kallab, C.; Ghawi, M. Generic key performance indicators. In Proceedings of the 2014 3rd International Conference on e-Technologies and Networks for Development, ICeND 2014; 2014; pp. 165–171.

[5] Faveto, A.; Traini, E.; Bruno, G.; Lombardi, F. Development of a key performance indicator framework for automated warehouse systems. In Proceedings of the IFAC-PapersOnLine; 2021; Vol. 54, pp. 116–121.

[6] Franceschini, F.; Galetto, M.; Maisano, D. Management by measurement: Designing key indicators and performance measurement systems; 2007; ISBN 9783540732112.

[7] A Markdown Editor for the 21st Century | Zettlr Available online: https://www.zettlr.com/ (accessed on Mar 9, 2021).

[8] Obsidian Available online: https://obsidian.md/ (accessed on Mar 9, 2021).

[9] Notion – One workspace. Every team. Available online: https://www.notion.so/ (accessed on Apr 15, 2022).

[10] Frazelle, E. World-Class Warehousing and Material Handling; McGraw-Hill, 2016; ISBN 9780071842839.

[11] Staudt, F.H.; Alpan, G.; Di Mascolo, M.; Rodriguez, C.M.T. Warehouse performance measurement: A literature review. Int. J. Prod. Res. 2015, 53, 5524–5544, doi:10.1080/00207543.2015.1030466.

[12] Hazwani, K.N.; Rahman Noorul, A.; Fitri, S. Warehousing Productivity Assessment on Logistics Service Sector. Adv. Transp. Logist. Res. 2018, 1, 889–903, doi:10.25292/ATLR.V1I1.90.

[13] Karim, N.H.; Abdul Rahman, N.S.F.; Md Hanafiah, R.; Abdul Hamid, S.; Ismail, A.; Abd Kader, A.S.; Muda, M.S. Revising the warehouse productivity measurement indicators: ratio-based benchmark. Marit. Bus. Rev. 2021, 6, doi:10.1108/MABR-03-2020-0018.

[14] Falegnami, A.; Tronci, M.; Costantino, F. The occupational health and safety risks of ongoing digital transformation. A knowledge management software powered literature review,. In Proceedings of the XXVI Summer School "Francesco Turco" – Industrial Systems Engineering. 08-10 September 2021; 2021.