Using Indoor Positioning Systems (IPS), for Supporting the Digital Mapping and Evaluation of Material Handling Processes, in Intralogistics Systems

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Abstract: The need for process digitalization, with the solution of Industry 4.0, has impacts for logistics companies. The need of the retrieving dynamic information about the position of different objects has also appeared in intralogistics. In a facility, dynamic data from the position of moving material handling machines can provide useful information for companies enabling the optimization of related processes. Indoor positioning can be implemented using different technologies and solutions, but the accuracy and reliability of existing indoor positioning systems (IPS) vary significantly and can be affected by many factors. This is a disadvantage for IPS supported online reproduction of manual analyses. This article will present the possibilities of using data from IPS, through various logistics analyses. It will be shown that analytical solutions can be implemented using location coordinates and the time data from IPS.

Keywords: intralogistics; indoor positioning; material flow system; spaghetti-diagram

1 Introduction

There has always been a constant drive for progress, as in the desire to apply new ideas and technological innovations as quickly and widely as possible, in the industry (industrial revolutions). The reasons for this are, on the one hand, to achieve the highest possible degree of competitiveness and market share within a market and, on the other, to increase efficiency and productivity. That is not different within the area of intralogistics [1].

Intralogistics encompasses the internal processes of a company's site in which material and product flow take place. Within a site, there are usually several plants working together, within and between them, it is necessary to manage the flow of products [2]. The various stages of a product's route within the company, usually takes place in different locations. Storage tasks between the production phases have to be carried out to bridge the time gaps. These storage tasks can be realized at disparate locations. To ensure this flow of products, different material handling tasks have to be carried out, which can be achieved with different auxiliary tools, machines, and equipment [1].

There are various innovations in the many sub-areas of intralogistics, but the focus is specifically on material handling objects in this paper. Using various identification technologies, information concerning the physical position of a product can be easily obtained. This information is (usually) not continuous, but it is linked to specific positions, points and times. This is why real-time tracking of material handling equipment can be important [3]. The location data set can be useful for past, present, or future use. It can support the operation of different logistics systems, and facilitate the autonomous operation. By evaluating data from specific logistics processes, quantitative information about the system in operation can be obtained, whilst historical data can be used to simulate a system that is to be expanded, thus providing accurate data on the performance and efficiency of the material handling system. Only in such kinds of systems, can it be possible to provide a digital representation of the logistics process or a whole system that can support continuous and real-time positioning with high accuracy [3].

The aim in this research is to collect data using real-time indoor positioning systems regarding the motion of different objects (operators and/or machines) applied in the material handling in an intralogistics system and after preprocessing to use it to create automatically, without any additional human effort the well-known spaghetti-diagrams and the related analytics which is nowadays a popular tool in the material flow analysis in the lean-based current state investigations. We believe that these systems can be used to extract a lot of additional information from the motion of objects (mainly material handling machines) and significantly reduce the human effort and time required, in contrast to traditionally recorded analyses. We assume that this kind of automatic mathematical mapping supported by indoor positioning systems has many advantages over manual mapping. There are many differences not only in the way measurements are taken, but also in the accuracy of the data and the evaluation possibilities.

By mathematically mapping the material flow, we can open up many possibilities. We can construct a where-to-where matrix showing how many times each transaction (from A to B) occurred in the process. In addition, the sender and receiver locations of the process can be plotted. We will also be able to quantify the relationships between the workspaces. We can also determine the degree of cooperation, even dynamically, as a value that varies with the process. Furthermore, the mathematical mapping can show whether the pre-assigned tasks have actually been carried out in the order in which the operators assigned them. In addition, the stage of completion of the task can also be checked at a given moment.

An important step in digitalization, is to track movements on the production floor. The traceability of identified objects is built-up from status and movement tracking. For the latter, indoor positioning systems can be used [4]. IPS devices provide a set of inputs to build up and operate a company's digital twin. However, for a digital twin to work properly, it needs a stable and reliable data set that does not allow for scattering of up to several meters [5]. Because of this, we aim to create a suitable mathematical reproduction of the material flow system (graphs, matrices). In this paper, we attempt to do so. However, to do so, we need to understand the obstacles and define the challenges that make it hard to create an automatic mathematical model, since this is the only way to model the process. We are not aware of any IPS supported tool or solution that explicitly aims at mathematical representation. The well-known applications supported by IPS in logistics usually produce heatmaps of the movement of objects in the area under study and give various metrics as output. Thus, we want to explore further possibilities for deep analysis of logistics processes beyond tracking moving objects. In this work, we are not concerned with the autonomous control of moving objects, nor with the direct tracking of products.

Structure of the paper and definitions of goals:

- Introduction to indoor positioning systems: Our aim is not to describe the different technologies, but to collect information on how they are used for analytical tasks (mainly in the field of intralogistics)
- Manual spaghetti-diagrams: creation and analysis options
- General use of data from the IPSs and a case study: digital spaghetti-diagram and other analysis options

2 Indoor Positioning Systems (IPS)

The need for the IPS may have arisen because stand-alone GPS positioning inside buildings cannot provide reliable positioning data [6]. However, with the right equipment (down-converting repeaters and up-converting receiver) placed inside the building, accuracy of less than 1 meter can be achieved [7]. On one hand, the need for these devices is so great because of the growing role in the industrial and the private life of self-propelled, autonomous machines and devices. In this way, automatic and autonomous material handling equipment is also gaining ground in intralogistics [8]. In addition, IPS are also gaining importance due to the digitalization of processes. These increase the value for companies of the information they need to determine where each moving object is at any given moment in time, as this is an important prerequisite for their control. This information is dynamic information describing the process. On the other hand, the most important focus of this paper is to investigate the extended possibilities of the effective application of IPS in the operational monitoring of material handling objects. IPS systems allow for a complete digital mapping of a motion process, which can open up completely new and different analysis possibilities than in the case of traditional ones [9].

Real-time IPS-s are a set of devices using different technologies to determine the position of a moving object with a given spatial and temporal accuracy. Usually, these devices consist of transmitters and receivers that communicate with each other using different signals and are connected to a computer, where the current position of the tracked objects can be displayed visually [9]. With these technologies, not only is a given position of an object under test obtained but a measurement time instant is associated with the given position data [3]. A new dimension (time dimension) is thus added to the space dimension. With this new dimension, information that manual measurement could not obtain is available and new indicators can be defined and measured. For this reason, in this paper, we compare the manually recorded and evaluated spaghetti-diagrams with the evaluated results of the data from the IPS.

The basic user requirements for IPSs include accurate positioning, adequate frequency of location data retrieval, minimization of latency, reliability, small size, reasonable price, and energy efficiency. The continuous development of these products is proof of this [10]. There are currently several technologies for indoor positioning, different IPS devices may all have different characteristics [11].

2.1 State of the Art

There are already more than 20 products available in the market that provide indoor positioning solutions using one or more technologies and at least 8 products that can be used specifically in intralogistics environments for analysis tasks and optimization of material handling processes. These complete IT solutions include distance measuring devices and dedicated software using position data, which can provide various information based on the movement of the observed objects.

The IPS products offer a variety of different solutions to complement industrial positioning analysis [9]. Table 1 summarizes some possible applications, tools that may be useful for the analysis of the material flow. These IPS products can be used to produce a digital spaghetti-diagram showing the paths used by different material handling machines. In addition, the load of the material handling areas used can be provided with a heatmap. The various analysis and monitoring devices can also provide information on the average speed of the machines, the ratio of loaded and empty passes, or even the idle and run times. However, companies are also developing additional customer-specific tools. Another common additional function is the route and machine resource optimization using the data. However, companies can not only extract concrete statistical results from their material handling processes by using these systems, but also gather information on the routing habits of forklift drivers, which can be used to analyze the routing times and the reasons for the losses. With some specific products, it is possible to train forklift drivers with virtual reality (VR) assistance and introduce restrictive and safety regulations by introducing zones with different degrees of risk [12]. In this paper, we show that there are several ways of using timestamped location data that IPS users can create.

SYSTEM / FEATURE	HID	sewio	Marvelmind	arcGIS IPS	Zebra	Atlas IPS	Ubisense	situm IPS	Blueiot	navigine	inpixon, intranav	litum	bluebotics	dragonfly	indoorway
visualisation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
heatmap	✓	✓	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓	✓
KPI from transaction dat	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓
KPI from time data	✗	✓	✗	✓	✓	✓	✓	✗	✓	✓	✓	✓	✗	✓	✓
wayfinding	✓	✓	✗	✓	✗	✗	✗	✓	✓	✓	✗	✗	✓	✗	✗
zone monitoring	✗	✓	✗	✗	✓	✗	✓	✓	✓	✗	✓	✗	✗	✗	✓
proximity alert	✗	✓	✗	✗	✗	✗	✗	✓	✓	✗	✗	✓	✗	✗	✗
	3	7	1	3	3	2	3	5	5	3	4	4	3	4	5

SYSTEM / TECHNOLOGY	HID	sewio	Marvelmind	arcGIS IPS	Zebra	Atlas IPS	Ubisense	situm IPS	Blueiot	navigine	inpixon, intranav	litum	bluebotics	dragonfly	indoorway	
WiFi	●							●		●						3
RFID					●										●	2
Bluetooth								●	●							2
BLE	●				●					●						3
UWB		●			●	●	●				●	●			●	7
GIS				●												1
smartphone sensors								●		●						2
magnetic fields								●								1
chirp RF											●					1
laser rangefinder															●	1
laser scanner													●			1
computer vision														●		1
ultrasound, RF			●													1
WhereNet					●											1

Figure 1

Solution overview [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26]

According to Figure 1, existing industrial IPS solutions can provide different options for customers. Based on the information on the websites, ***sewio*** may offer the most features to users, but almost all products are also designed to meet customer-specific needs. It is important to note that these systems use different technologies (UWB, BLE, RFID...) and can provide different levels of accuracy in location data. UWB is the most used technology and some products use more than one technology. Two of the products listed also use IMU for positioning. With accelerometer, magnetometer, and gyroscope data from a smartphone IMU sensor, a higher accuracy of positioning [27] and a higher update frequency can be achieved [28]. The advantage of IMU is that it is lower cost, does not require such equipment as other IPS systems. One of the major challenges of IMU positioning is inaccuracy due to errors. However, this can be greatly improved by using different algorithms, error compensations and filters [29].

2.2 Literature Review

IPSs can be found in a wide range of literature. There are many technology overview articles available, which either do not mention or only mention IPS systems on the market and give a general description of the characteristics of the technologies used in each system. The other possible classification category is represented by sources that specifically describe an existing indoor positioning product. Understandably, fewer of these are available [30]. In Table 2, we have collected the most relevant literature we found. We have identified two main groups of literature: 'General technological summary' and 'Ready-to-use systems'. We have further classified those dealing with specific systems into subgroups: basic statistical and other measurements, and measurements on intralogistics.

Table 2

Literature overview

Category	**General technology summary**	**Examining a system**		
Articles		**Basic statistical measurements**	**Other measurements**	**Intralogistics field measurement**
2012 [31]	X			
2013 [32]		X	X	
2016 [33]	X			
2017 [34]	X			
2017 [35]	X			
2017 [10]	X			
2017 [36]				X
2017 [37]		X	X	
2018 [38]		X	X	
2018 [39]	X	X	X	X
2018 [6]	X			
2018 [40]				X
2019 [41]		X		X
2020 [42]				X
2021 [43]		X		X
2021 [44]			X	
2022 [45]		X		X
2023 [46]			X	
2024 [30]		X	X	X

The most important conclusion from Table 2 is that there are only a few literature where actual intralogistics measurement applications have been identified. No one was found on testing the usage of ultrasound technology. In contrast to the previous research results, our goal is to develop a possible automated data processing workflow using only the timestamped location data. Our goal is to create a digital spaghetti diagram using this preprocessed data set, and – unlike a manually prepared spaghetti diagram – to collect additional information about the material flow system in a fully automatic way. Furthermore, we think that IPS will be one of the most dominant core technologies for digital logistics applications of the future, such as digital twins. In this paper, data was collected online and evaluated later. The aim is to map the processes in real time using an automatic evaluation program. In this way, a real-time, automatic and bi-directional data flow can be achieved, which is essential for the digital twin [47].

3 Observing the Material Flow: The Spaghetti-Diagram

The simplest way to analyze the flow of materials is to use a spaghetti-diagram, a visual representation of the flow of different objects (people, papers, bills) [36]. To create a simpler spaghetti-diagram, only a site plan of the area that the object under study is travelling through and a writing utensil are needed. A person must be present at all times during the process to draw the current position of the object being observed, which outlines the path being routed. In this case, it is always advisable to follow the different objects with distinct colors or lines [48]. The object of interest may be other in different spaghetti-diagrams. It may be a matter of tracking a single object for different lengths of time, or even multiple objects operating in a given area together [36]. If the movement of an object over several hours needs to be recorded, even if it passes through the paths concerned several times, several drawings must be made, even broken down by hour. Figure 2 shows spaghetti-diagrams. The result of spaghetti-diagrams is a site plan that includes the paths of the object(s). However, more information and conclusions can also be drawn from a single diagram. In addition to the clear paths, we can also obtain the density of material handling transactions on each path, which characterizes the load on that path. Filtering out and eliminating over-density points is an important task, which depends largely on the properties of the process and the characteristics of the area. For post-processing, a spaghetti-diagram can be used to create a graph. In this representation, the vertices can be the sender and receiving points affected by the forklift. Evaluating such a hand-drawn spaghetti-diagram of an 8-hour shift and extracting numerical indicators requires a considerable investment of time. This also proves that if IPS data were used to replace these manual observations, the data collection and the investigation could be done automatically, so money and time could be saved.

Figure 2
Spaghetti-diagram [48, 49, 50, 51]

4 Processing Possibilities of Location and Time Data to Determine the Properties of Material flows

In the following, the analysis options will be presented that can be performed without any additional analysis software. Figure 3 shows the possible steps of data processing.

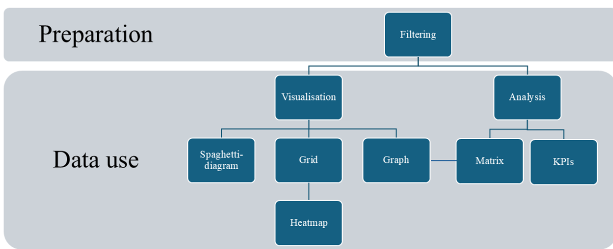

Figure 3
Possible steps of data processing

The following solutions use only MS Excel, Visio and data from the IPS: the 'x' and 'y' coordinates of the tracked object and the corresponding timestamps. The extracted location data are retrieved in chronological order. To perform an analysis of a process, it is necessary to define a time interval within which a processable amount of data is generated and perform various filters on this data to ensure that it is available in the right quality [44]. After this preprocessing, the data set can be used for various analyses and to calculate process characteristics.

4.1 Visualization: Digital Spaghetti-Diagram and Heatmaps

A spaghetti-diagram can be drawn without modifying the data [52], but in the first step it is recommended to examine the data series from the object tracking process of the desired duration. The resulting data series should be subjected to some smoothing (for example, using a moving average in the time series) to eliminate outliers and possible misrepresentations, but it is important to note that after smoothing, a sufficient amount of data and accuracy is still required. Looking at the unfiltered data sets of the recorded processes, it can be concluded that a different amount and depth of data preparation is required depending on the size of the area and the nature of the environment. The goal is to use a variety of procedures to provide a data set that shows only minimal deviation from the routes actually travelled.

It is advisable to first rid the data set of outliers for filtering, due to the measurement error. These are points that can be taken with an accurate knowledge of the location, as they are likely to fall on non-traffic routes but relatively further away from them. This filtering can be performed by subtracting specific coordinate areas from the data set, but this reduces the number of measurement coordinates used. After that, we can perform various smoothing and averaging procedures on the data set to get as many routes as possible.

Once the smoothing is complete, a different spaghetti-diagram can be drawn to perform further analysis [36]. From the spaghetti-diagram of the entire process under study, spaghetti-diagrams can be extracted for specific shorter time intervals so that additional information on densities of transactions can be obtained in the shortened time intervals.

A heatmap with ’x’ and ’y’ coordinate axis can also be generated from the data series after performing the appropriate preparatory operations. The heatmap provides visual information on the time spent in each area by the observed object [12]. To do this, it is first necessary to take a grid, which must be assigned to the specific area where the object moves. When selecting the grid sizes, it is necessary to consider that the grid should be defined to represent the best way the main areas (workplaces) visited and the routes. A suitable solution to this may be to label all segments in the resulting grid with particular regard to the segments within which movement has occurred. By using grids with different gradients, different heatmaps can be generated.

4.2 Mapping of Material Flow: Graph and Matrix

Suppose the grid segments which contain the priority work areas have been known, such as different production machines or other privileged work points where manipulation is required during material handling (e.g., pallet depositing). In that case, the main sender and receiving areas of the process can be determined.

To determine the workload, the times spent in the specified grid spaces that belong to the priority work areas that we want to investigate must be summed. In this way, the percentage of the process duration can be obtained that was spent in a prioritized work area and the percentage that involved actual movement on the road network.

Another way to determine the work time composition is to know the exact coordinates of the prioritized areas and then to examine the time spent by the object within a given radius of the coordinate. However, in this solution, the times from the movement are already included in the workload, and therefore the information about the process is distorted.

Another advantage of the grid design is that, if the sequence of operations performed by the material handling operator is unknown, it is possible to determine the routes taken during the realization of the process, which can be used to deduce the order of the operations during the visiting of the prioritized areas. In this case, it is necessary to examine the evolution of the chronological order of the grid segments associated with each time point. Suppose a raster label to each second has been assigned in ascending chronological order. In that case, the order can be determined in which the object passes through the prioritized workspaces by examining the successive and returning labels. However, this does not give a result with 100% reliability.

Once the search sequence has been established, the resulting data series can be converted into a matrix format, showing where the object has started from (or arrived to), and how many times during the process. The rows and columns of the matrix are labeled with the highlighted work areas or the rasters. A numerical value is placed in a cell if the tracked object has moved from the row label of the intersection to the column label above the intersection. The numeric value represents the number of times of the movement associated with that grid field pair has occurred. This where-to-where matrix can form the basis for subsequent material handling task optimization, as it can be used to examine which round trips would have been appropriate for the material handling operator to make.

Other types of information can be extracted from the location data with time stamps and the above.

- Distance travelled, Idle times, Number of unloaded/loaded trips
- Average material handling velocity
- Using other data (e.g., weight): material flow intensity, material flow work, material flow efficiency, material flow performance [53]

5 A Case Study: Tracking a Material Handling Process

In our department, the Marvelmind Indoor "GPS" Starter Set Super-MP-3D indoor positioning system is already available for testing. This IPS uses ultrasound and radio signals in its operation. 6-8 position recordings are made per second. The positioning is done using mobile and stationary transmitters in terms of operation. The mobile transmitter is required to be fixed on the moving object under the test and emits ultrasonic signals during tracking. The distances are calculated using trilateration, a distance value that can be determined from the delays in the propagation of the ultrasound [54].

After the introduction to the Marvelmind IPS, the next task was to study the statistical characteristics of the IPS system. Spatial accuracy is the most important information for the analysis of the material flow, but there are different ways of determining this. To determine the spatial accuracy, we mainly performed point measurements [52], where we placed the moving transmitter on predefined points with given coordinates and then recorded the coordinates calculated by the IPS over a larger time interval (1-3 minutes). It is clear from the point-based measurements that it is essential to filter the output data of the IPS, as some environmental disturbances and interferences can negatively affect the measurements. Some of the measurements were carried out in an office environment and others in the large laboratory of the Department of Material Handling and Logistics Systems at the Budapest University of Technology and Economics. The measurements in the office environment were carried out on a maximum floor area of 1.5 m × 2 m, whilst in the laboratory it was possible to repeat the measurements on a 4.8 m × 6 m area.

To demonstrate the analytical possibilities identified above, it was necessary to define a process for testing. As a first step, a small site plan was prepared as a production area model, with 6 priority work areas. All elements of the recorded site plan fall within the rectangle stretched out by the four fixed beacons. The enclosing sides of the stretched rectangle are 2.33 m × 1.80 m long. The beacons are 0.115 m from the ground. In designing the testing process, we predetermined the order in which the vehicle (which model the material handling machine) would visit each priority area, and we also specified that the downtime at cells C1, C2, C3 and K would be limited to 10-30 seconds, the waiting time at the raw material storage area (A) would be more than 30 seconds. Before recording the process, we performed point measurements in the designated layout. We compared the actual coordinates of 11 predefined positions with those measured by IPS. The actual and measured coordinate deviations were found to differ by an average of 3 cm from the manually measured values, with a maximum deviation of less than 8 cm and a minimum deviation of 1 mm. The half-hour testing process was then carried out, during which 12657 locations were recorded. In Figure 4, the dot plot also shows off-track outliers, which were probably due to inaccuracy or signal loss due to non-compliance with the LoS requirement.

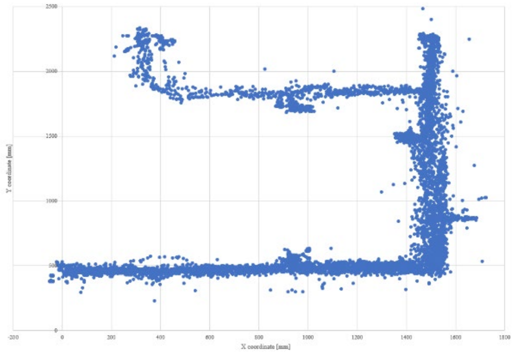

Figure 4
Office environment- Dot plot (N:12657)

The acquisition of the measurement grid preceded the development of the heatmap. This was done by first recording a suitable grid along the coordinate axes and using a labeling technique to label with numbers the fields of the grid in which movement had occurred, that is highlighting the fields covering the traversed paths. This was followed by a summary of the time spent in each field of the grid, which we then grouped into three categories based on the total. A red-orange-green scale has been applied based on the average dwell times. Where, based on the threshold values to the fields with larger times, have been assigned the red, and the fields with lower times have been assigned the green color. In this test, two types of grid assignments were examined. The left side of Figure 5 shows that two rows of fields appeared on the access road connected to the finished goods warehouse, with 4 fields having values below 10. That is why it was necessary to use a grid assignment where no redundant fields appear parallel to the main fields on the access roads. In the second case, no redundant fields were created in this allocation. The right side of Figure 5 shows the final heatmap.

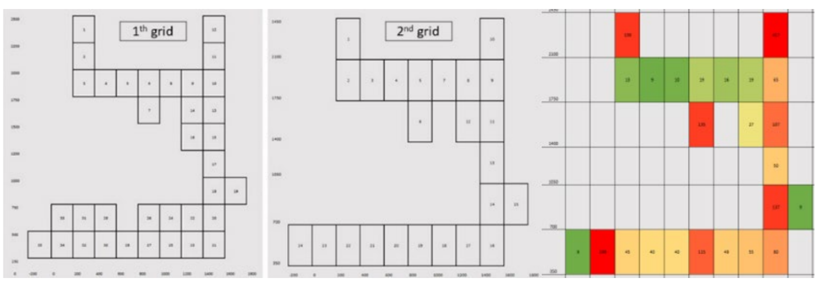

Figure 5
Heatmap construction

Based on the number of fields assigned to seconds in the grid, a list can be drawn up showing the order in which the object visited the different fields. From this data series, a where-to-where matrix can be constructed, in which a numerical value is shown in the intersections of the given rows and columns if the object under test went from the field of the given row directly to the field of the given column. In the matrix cells, the different values indicate the number of times the object has moved between the given pairs of fields. Figure 6 shows the number of transactions projected onto a grid and a graph, where the diameters of the nodes and the intensity of colors refer to the sum of the handled transactions in the node, moreover the linewidth of the edges and the intensity of the colors referring to the number of transactions between the nodes.

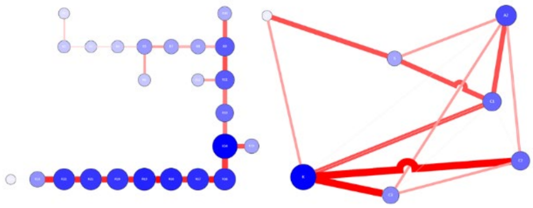

Figure 6
Number of transactions (rasters and cells)

The time spent in different fields of the grid is also possible to calculate during the evaluation of data. When calculating the times, however, it is necessary to take into account that where the investigated field is in direct contact with the road network, it is examined within a narrower boundary of how many times the moving beacon has registered there. Thus, it is necessary to restrict the boundary points to at least one side. On the other hand, in the evaluation, it can also take into account that in priority areas, the "dwell time" should only be counted if it was greater than a given minimum value (for example, 5 seconds). The main values calculated are shown in Figure 7. In the graph, edges represent the operational time in the node and lines represent the travelling time between the nodes / dedicated points.

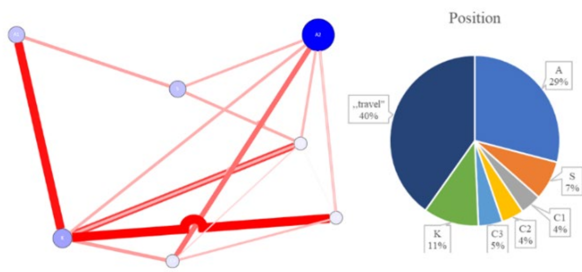

Figure 7
Time-based occurrence per workplace

The same process has been recorded in the laboratory of the department on a floor area of 4.8 m × 6 m. In this case, the test process was recorded using an RC car (which was used as the model of a material handling machine). The moving transmitter was placed on the RC car, and the data was recorded in this way. On the left side of Figure 8, the dot diagram containing all the positions from the measurement, the positions that are definitely off the traversed route are highlighted in red. These positions need to be filtered out of the data set during data preparation. After filtering out the outliers, the values in the data set were averaged in seconds. The right side of Figure 8 shows this filtered chart.

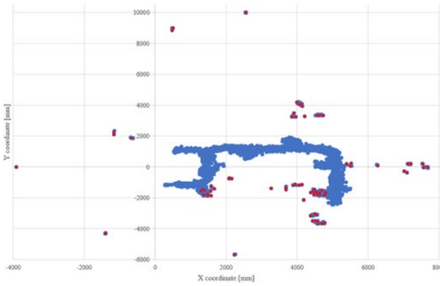

Figure 8

Laboratory environment and Filtered- digital spaghetti-diagram (N1: 13914, N2:1330)

An examination of the data set followed this. In the recorded process, the moving object visited the selected areas in a predefined order. Here it is necessary to examine whether the same order is obtained from the data set. Figure 9 shows the laboratory test environment.

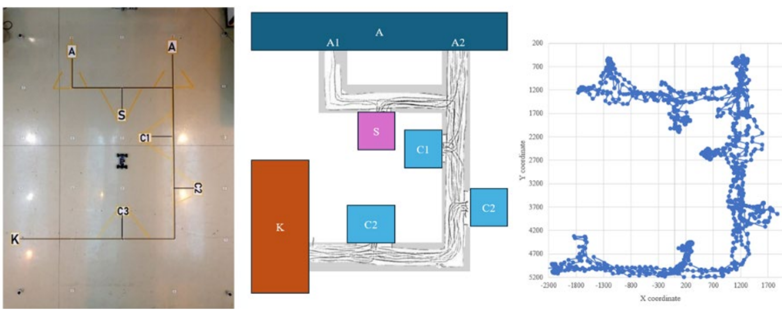

Figure 9

Laboratory test environment with spaghetti-diagrams

During the process, the moving object visited the highlighted areas 47 times. First, a radius of 300 mm was fixed at the positions belonging to the areas. At that time, however, there were 10 deviations from the predetermined process in which it did not always perceive itself to be in areas C3, C1, and K. Therefore, it is necessary to modify the radius defining the areas, which has involved enlarging the areas. Thus, there were only 2 differences between the original and the received visit sequences.

One of the interesting things about the measurement was that the most critical point was the ‘S’ field in the grid. Sometimes the ‘x’ and sometimes the ‘y’ coordinate showed very different values from the actual ones. We suppose that in this area, somewhere in the ground or in the basement, it is likely that there could be an ultrasonic or radio frequency interference object. Finally, an aluminum column was attached to the remote control (RC) car, to eliminate this error. This attachment placed the transmitter half a meter off the ground. There was even less signal loss in this case, and the data set was easier to clean and apply for further evaluation.

Conclusions

Our aim was to compare the spaghetti-diagrams created manually and use MS EXCEL with the data from an IPS. Not all IPSs are supplied with analysis software, but users can create an application to help them process location data. In this paper, we have defined the necessary steps for using data from the IPS. With the help of a computer application, using IPS data, we have shown not only that the trajectory travelled by the forklift truck (spaghetti-diagram), but also other valuable information is obtained, with much less post-processing and in less time. In a well-known area, we can estimate which sub-areas could be sender or receiving locations for the forklift, which can be used to produce a mathematical representation of the material flow.

One of the relevant advantages of such an application is that it does not require a dedicated human resource, who has to follow the movements draw and make notes of the most interesting or unexpected situations over a given time interval. It also provides the user, visibility of the density points and unlike a hand-drawn diagram, a clear, analyzable raw data set, from which the numerical values can be easily extracted. Analysis of the data from the IPS system has shown that, unlike a manually generated spaghetti-diagram, much more information can be extracted from the material handling flows. A comparison of manual and IPS-supported data collection is shown in Table 3.

Table 3

Comparison

	Making manual Spaghetti-diagram	**Making digital Spaghetti-diagram using IPS**
Data collection	manual	by machine
Data type	primer data	primer data
Need for equipment	minimal, low	High
Need for HR	high	Low
Environmental circumstances	non-sensitive	Sensitive
Accuracy	lower	Higher
Complexity of evaluation	difficult	simple

Time required for evaluation	plenty	none/short
Direct outcome	hand-drawn diagram	digital diagram
Need for digitalization	yes	no
„On-the-job" information	yes	no
Transaction data	no	yes
Time data	no	yes
Quantity of data that can be recorded	limited	big
Generating heatmaps automatically	not possible	possible/available
Mapping of material flow graph automatically	not possible	possible
Generation of other KPIs	not possible	possible
Number of objects	mostly 1	up to several

For this reason, in our future research, the aim will be to create an automated file, that can be managed in MS EXCEL, capable of handling location and time data, from any IPS system, using any technology.

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