SPAGHETTI DIAGRAM APPLICATION FOR WORKERS' MOVEMENT ANALYSIS

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Various methods and tools can be used for production and assembly workstation layout evaluation and design support. The paper describes the concept of worker movement analysis tool based on Spaghetti diagram as a result of international project focused on lean production. The presented solution allows to create diagrams and evaluate them according to time, distance, number of visited places, etc.

Keywords: lean production, Spaghetti diagram, assembly, worker movement

1. Introduction

In terms of competitiveness, various factors decide about the success or failure of the company. These factors relate to the product [1] (technical, functional, operational, price, quality parameters, etc.) as well as the manufacturing process itself and the people who work in this production. The goal of various tools is to find and remove reserves [2, 3]. If we focus on the person as an important factor affecting the production, we will need to search for ways to optimise the worker activities. One of the challenges in this area is the analysis of worker or workers movement at the production area and the final aim of improving the parameters of a solution by identifying and removing activities that do not directly contribute to the creation of the product value. It regards the application of lean manufacturing principles at the stage of evaluation of current layout respectively new layout proposals of the production. Layout has influence on performance and competitive advantage of firms [4]. To propose layout there exists various methods. Every method has own advantages and disadvantages [5]. There is possible to propose many layouts and then it is necessary to choose one. It is difficult task because when we consider different criteria, different layout can be considered as a right one. There are various suggestions e.g. [6, 7] to choose "right layout". Firms are nowadays in very challenging environment. Firms are asked for mass customisation, high speed of production and high quality of products. These demands require high flexibility of firms. This flexibility must allow layout changes according to produced products also. To choose "right

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layout" there are various criteria. One of the criteria can be the workers´ movements. Spaghetti diagram is an aid to support their visualisation and analysis.

There appear some modern accesses how to fulfil above mentioned demands. One of them is concept called Industry 4.0. - Digitalisation for productivity and growth. This concept depends among other things also on:

- "The application of information and communication technology (ICT) to digitise information and integrate systems at all stages of product creation and use (including logistics and supply), both inside companies and across company boundaries;" [8]
- "Collection of vast quantities of data, and their analysis and exploitation, either immediately on the factory floor, or through big data analysis and cloud computing."[8]

In accordance with application of ICT and data collection and their analysis, software application for workers' movements analysis was proposed and created.

2. Lean Production

Lean manufacturing or lean thinking [9, 10] has its origin in the concept to achieve better economic results with a special focus on waste elimination. The concept of waste (Mudas) is based on Toyota production philosophy by Taiichi Ohno [11], which was later identified as Lean Production or Lean Thinking [9]. In principle, there are seven basic types of waste:

- Transport, which does not add value to the product and therefore the costs associated with transporting are counted into waste.
- Inventory, e.g. stocks of materials, unfinished products during the manufacturing process as well as finished products in stock.
- Motion, thus any movement of the product which does not add to the product value.
- Waiting, i.e. any kind of waiting.
- Over-Processing, i.e. added value of products, that the customer does not actually requires.
- Overproduction, namely the production of more products than necessary.
- Defects, i.e. products or services are different from customer requests or from desired specifications.

To eliminate waste, there is a range of support methods and tools such as 5S method, Poka-Yoke, Just in Time, Kaizen, Jidoka, etc. First step to eliminate waste is to identify and show them. For such purpose can be used Spaghetti diagram.

3. Spaghetti diagram

Spaghetti diagram, Spaghetti chart, Spaghetti model or also Spaghetti plot is a method to view the movement of the object in the system with help of a line [12]. The surveyed moving object may be a worker, material and so on. A system in which such object moves can be a production area, part of a building, or workshop. The result resembling spaghetti gives its name. Fig.1 shows an example of Spaghetti diagram [13].

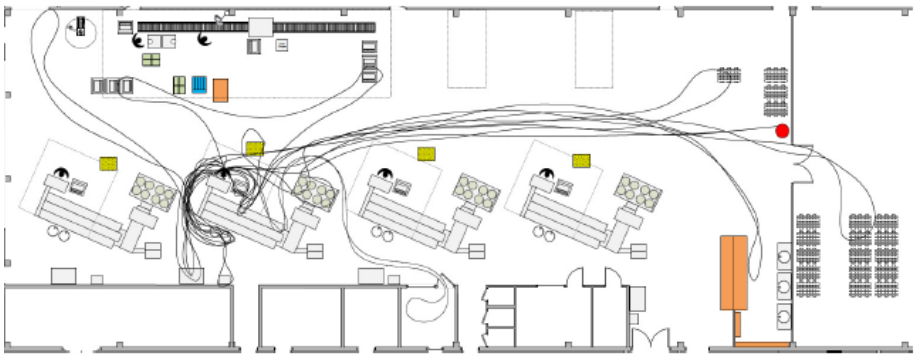


Fig.1 Example of Spaghetti diagram [13]

By using Spaghetti diagram, we can track the movement path of products, workers, intermediate products, etc. It is also possible to use different colours for various products, workers or technical means and track the movement at different times. After the analysis we can identify the movement lengths, number of movements, overlapping and crossing movements and their characteristics according to the chosen classification. Applying the result of the Spaghetti diagram, we can identify inefficient movements and ineffective areas, eliminate the number of staff, and make changes in the work organisation or workstation layout.

4. Concept of tools for worker movement analysis

The concept of a tool for the worker or workers movement analysis is based on the principle of Spaghetti diagram. In the first phase it is necessary to specify the basic parameters of the analysis. The basic scheme of possible variants is given in Fig.2.

In the proposed concept we can assess:

- several variants of workplace layout,
- change of workplace layout,
- change of the work organization,

- other combination of changes.

In terms of necessary input data can be worked on the basis of:

- 2D / 3D drawings with accurate dimensional characteristics,
- sketches of layout without dimensional data,
- 2D drawings with basic dimensional data e.g. VISIO,
- other basis.

The process itself which is analysed can be:

- fully-functioning workplace or workplaces,
- proposal of new workplace layout,
- real existing workplace and new workplace,
- other combination.

From the worker's point of view we can realise:

- analysis of the movement of one worker in one layout variant,
- one worker in several layout variants,
- more workers in one layout variant,
- other combination.

The concept of worker movement analysis enables to analyse several aspects. The first aspect is the movement plotted in the layout of the scheme in the form of lines. This aspect is in the proposed concept supplemented with:

- number of worker movements including the classification of individual movements according to its own classification scheme,
- movements distance calculated from a variety of sources, such as the precise dimensional data based on the drawings.

The other important aspect that is part of the concept is the time required for each movement of workers, which can be entered directly by monitoring activities in the workplace. If the input is only a proposal, e.g. real time data cannot be obtained because the workplace is only at the stage of the project, we can enter data of the estimated time.

The system allows to determine distances without being directly present in the workplace. If we have a picture of layout in scale and we know which movements are carried out and their sequence, we can determine the distance only using the Excel application.

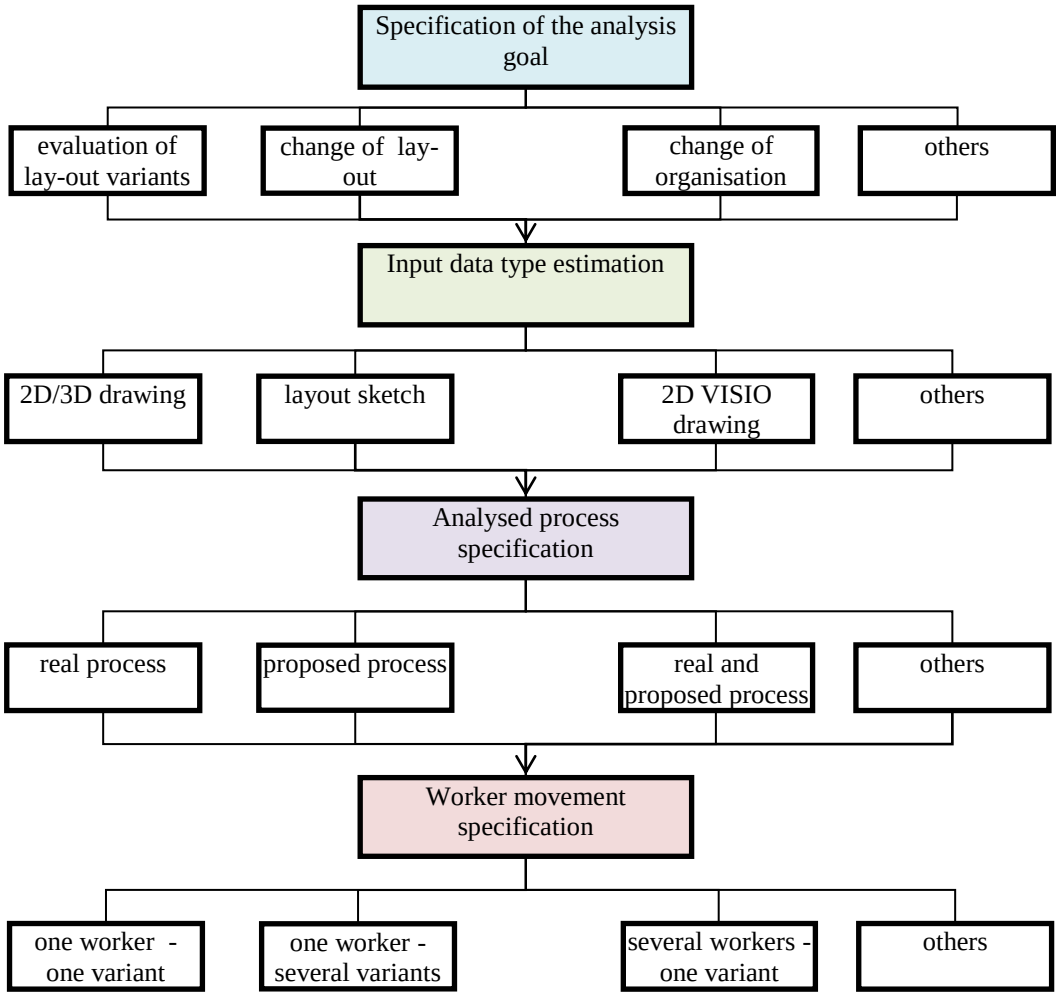


Fig.2 Scheme of worker movement analysis task variants

If we have a drawing of layout in scale, the tool can be used directly in the workshop proposal because such information is sufficient for the analysis.

5. Excel application for worker movement analysis

For the implementation of the concept has been processed the Excel application. Application is combination of Excel functions and VBA macros. Application fulfils following identified requirements:

- easy application and use of all its functions,
- the possibility of easy expansion and replenishment by users,
- compatibility with other applications to support Lean Assembly,
- ability to integrate applications into a larger unit.

The first task is to load the layout. The second task is to define individual points – places in the layout to or through which the worker moves. Fig.3 shows an example of assembly workstation layout loading with the principle of determining the coordinates of individual points.

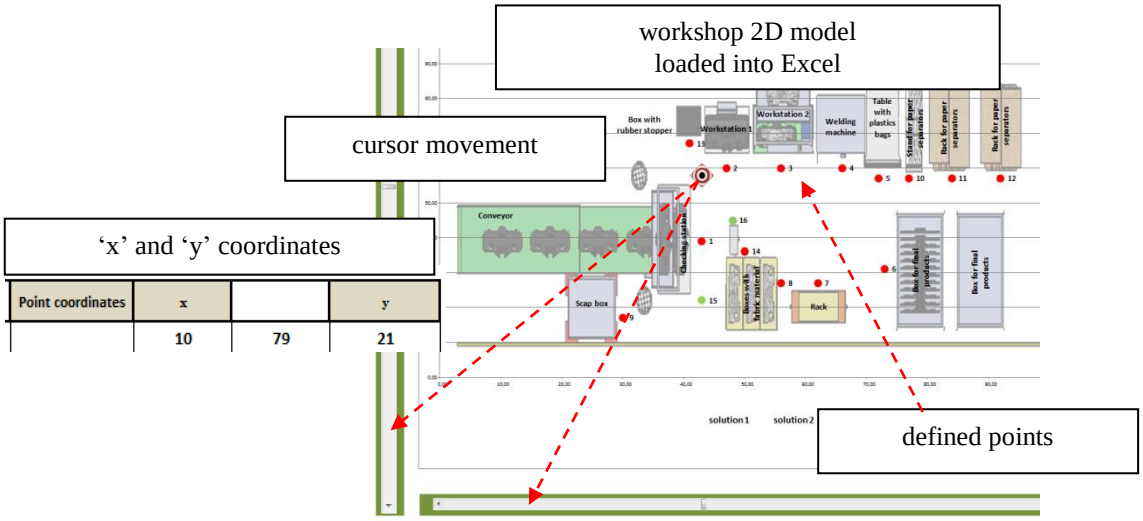


Fig.3 Print screen of Excel application - points definition

In the further procedure it is necessary to plot the movement of workers. In Excel application is the movement drawing performed automatically by selecting the start and end point of the movement. Points are available in the menu (Fig. 4). In case that the analysis is carried out in the existing production system or part thereof, it is also possible to specify the start and end time of each defined movement. In Excel for this purpose are available two basic macros - START and STOP, which can be activated by pressing the relevant buttons.

The application provides an evaluation of the analysis and when there are considered various options it also offers their comparison. It is, of course, possible to obtain data such as total time, number of movements, the total number of visited nodes, their order and the maximum distance.

Fig.4 Principle of movement definition in Excel application

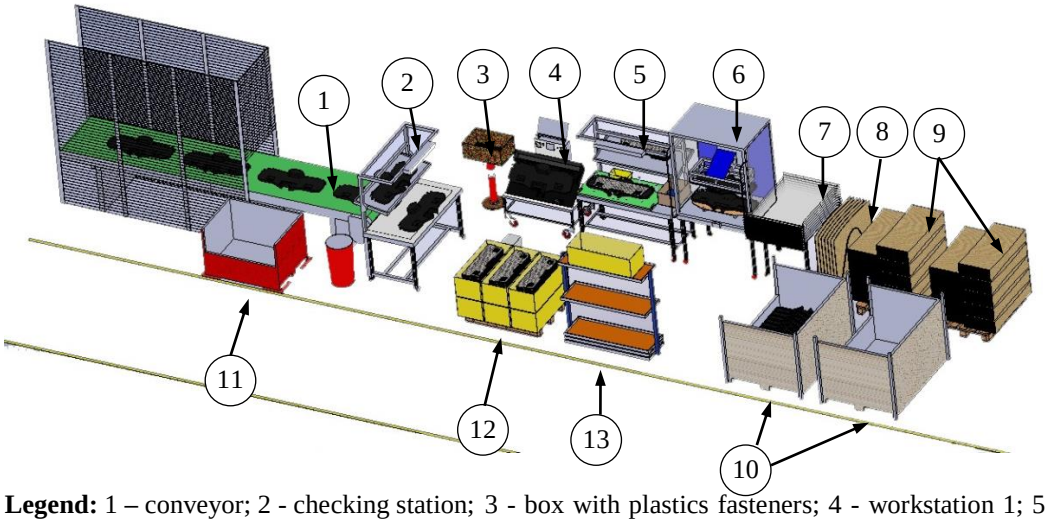
6. Workers' movements analysis in workshop

The test of proposed system for worker movement analysis was realised in the company Eurostyle Systems Slovakia Ltd. based in Liptovský Mikuláš. The company is a supplier of components for the automotive industry. The workplace for verification of the proposed system is the workplace for assembly of plastic panel that is mounted in the back door of Peugeot 208 which is produced in the PSA Peugeot Citroen Slovakia in Trnava.

Department at which the proposed program was tested is aimed at the assembly of automotive components (Fig.5) – the luggage compartment cover. In the process of its production, a plastic panel comes on the conveyor to the checking station where it is checked. If the panel is correct, it is transferred by workers to another workplace. If it is not correct, it is moved into the scrap box. Gradually the panel passes through six stations. The last station is a palette that stores packaged finished parts.

In the workplace there are pallets (buffer stores) from which components are transferred to individual workplaces. Two workers operate all six stations. They also supply the stations with necessary components. One worker operates the conveyor, checking station, workplace 1 and workplace 2. The other worker removes parts from the workplace 2, operates the welding machine, inserts parts in plastic bags and places packed parts into pallets. Since the maximum duration of the operation is 36 seconds, it is clear that the workers are constantly on the move.

At the end of the shift it is obvious that workers feel tired. To reduce the burden on workers as a result of walking, it was decided to analyse the movement of workers during work. The aim of this analysis is to determine the actual path of workers' movements. For this purpose it was used the above-mentioned software tool.



Legend: 1 – conveyor; 2 - checking station; 3 - box with plastics fasteners; 4 - workstation 1; 5 - workstation 2; 6 - welding machine; 7 - table with plastics bags; 8 - stand for paper separators; 9 - racks for paper separators; 10 - box for final products; 11 - scrap box; 12 - boxes with sound insulators; 13 - rack

Fig.5 3D model of analysed assembly workstations

At first, an image of 2D layout of the workplace was imported to Excel. Then there were defined the key points, that represent places where workers walk and where workers stand during the operation. Then there were subsequently recorded workers' movements. For recording was used video camera. Only a part of the shift was recorded, since it is a recurring activity. The recording of the entire work shift would be time consuming and would not bring any new information that would significantly affect the results of observation.

In the software, the movements are differentiated according to transport of the parts. Whether it is transport of the parts from station to station, or whether they are supply parts to station from buffer stores, and so on. Spaghetti diagram is generated according to input data of worker movements (Fig.6). In the diagram are plotted the paths of the worker's movements. It also calculates the distance travelled by the worker. The software processes the obtained data and on this basis generates results as a graph (Fig.7).

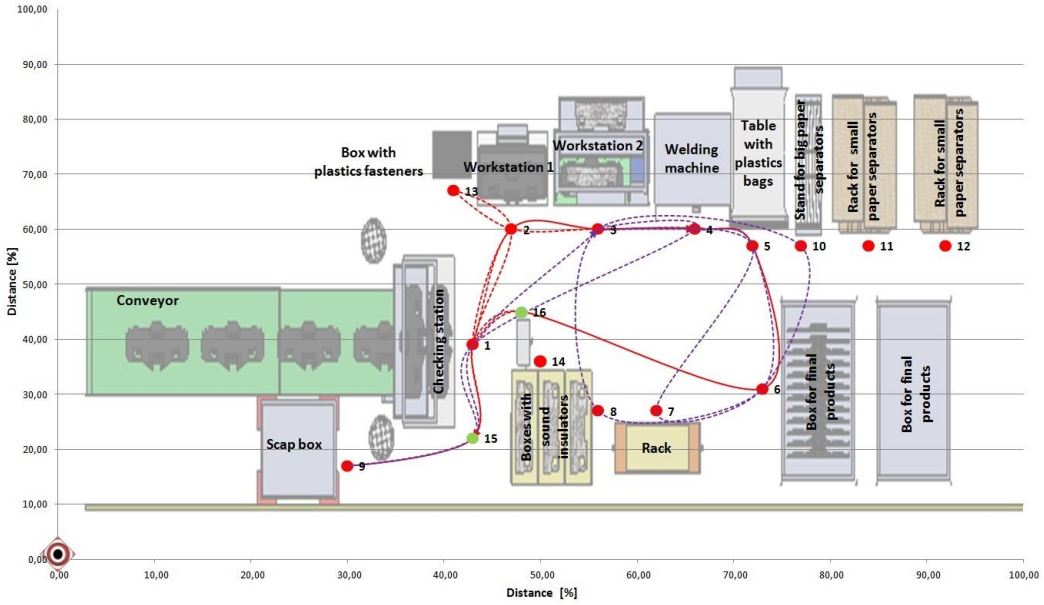
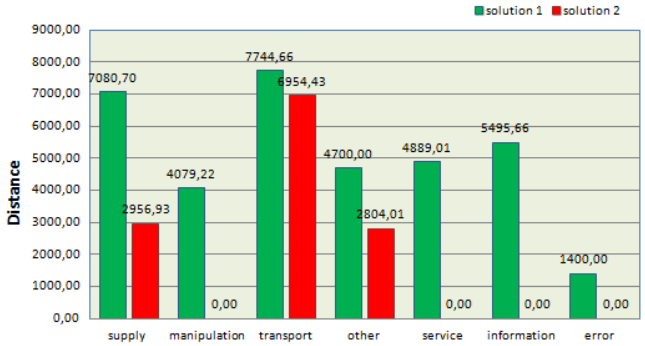
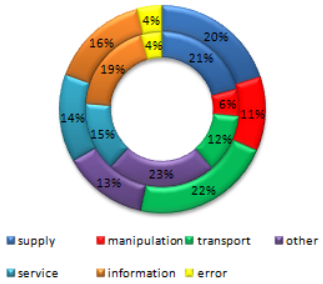


Fig.6 Spaghetti diagram of workers walking (red – worker1, blue – worker 2)



Distance of the two workers movement according to defined classification



Distance of 2 workers movement according to defined classification in %

Fig.7 Results of 2 workers movement analysis

From the graph we can see the distance the worker passed and into which category movements belong (transport, movement, supplies, etc.). The observation was performed for 10 minutes. Results are shown for a second worker. During this time, there were repeated the same movements and were made 10 pieces of product. During this time the worker walked a total distance of 68420 mm. Calculated on a manufactured item that is 6842 mm. Since per one shift, the average production is 490 units, the minimum distance travelled by workers for one shift is 3352.58 metres.

The total distance is even greater because of the need to supply workplace 2 with sound insulators from buffer stores. The station for components packaging needs to be supplied with plastic bags and the box for the finished parts must be supplied with separating cartons. It is also necessary, in case a defective piece occurs to take and put it into Scrap box. Since a faulty piece can be detected by a second worker at the welding station it is needed to increase the overall length of the distance by the distance which the worker must walk to Scrap box and go back to workstation 2.

Supplying workplace 2 with sound insulators needs to be done once for every 20 units produced products and the distance is 4500 mm. This increases the overall distance by 112.5 metres per shift.

Supplying with plastic bags needs to be carried out once for every 100 units products and the length is 4050 mm. This increases the overall distance by 201.6 metres per shift.

On average in one shift are detected 5 faulty units at the welding workplace. This increases the overall distance by 62.5 metres per shift.

When finished parts are placed in containers, separating cartons must be inserted between the individual pieces. In one container, there are 24 parts arranged over 8 units in three rows above each other. The separating cartons are inserted between the individual rows to separate the rows from each other, e.g. 1 carton for every 8 pieces of the product. This extends the overall length of 73.5 metres per shift.

Other cartons are put into each row to separate pieces from each other, e.g. one box for every other piece. As these cartons are smaller, after inserting a large carton, a worker takes smaller separating cartons (4 pieces) at once and puts them in a container. This extends the total length by 122.5 metres per shift. The total distance travelled by a second worker per one shift is therefore 3925.18 metres.

In terms of the lean production concept, these motions are waste of type Transport and Motion. It is therefore necessary to look for ways how to minimise them or completely eliminate. The first step to eliminate losses is their identification. The created Excel application allows to quantify the losses caused by the transportation and movement. The developed application helps turn attention to the right direction, i.e. to identify the biggest problems. Of course, it is not possible to eliminate all non-value added movement of workers, but it is possible to be able to reduce them. Consequently, it is possible to use the gained information as a basis for optimising the workplace in terms of layout, to achieve lower total distance the workers must walk during the workday, and thus less working time.

7. Conclusions

Based on experience with the application designed and created by authors for worker or workers movement analysis, it can be stated that this is a functional and fast procedure that is suitable for both, existing production or assembly workplaces or systems, as well as for workplace in the design process. Compared to the method of analysis, which is done with simple drawing movements by hand on paper, the created Excel application provides immediate evaluation on the basis of time or distance. The user can easily adapt the application and also integrate it into a more comprehensive system of methods and tools for lean manufacturing and assembly. The only larger disadvantage of the proposed application is that it does not allow rapid drawing of random and undefined movement of workers. In terms of opportunities for further development, it is planned to integrate Spaghetti diagram with assembly time analysis [14, 15] and also develop a version for the tablet to make the application more user friendly.

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