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METHODOLOGY FOR LAYOUT AND INTRALOGISTICS REDESIGN USING SIMULATION

Pawel Pawlewski

Faculty of Engineering Management
Poznan University of Technology
Ul. Strzelecka 11
Poznan, 60-965, POLAND

ABSTRACT

The paper describes a methodology for layout and intralogistics redesign using simulation. This methodology is composed of five stages: Topography, Product & Process, Linkages, Simulation, and Results. Key foundations are defined as PFEP (Plan for Every Part), Workstation as basic object for simulation, high level script language, cyclic processes, and 3D core simulation. The simulation model is built based on an earlier-prepared AutoCad drawing as background and on data in Excel about the Bill of Materials, PFEP, Container List, Assignment, and Operations. The simulation model is built using the developed template, which significantly shortens the modeling time.

1 INTRODUCTION

The paper is based on investigations carried out in recent years in the modeling and simulation of production and assembly systems, primarily in the automotive industry. The system under study involves multiple welding stations, where welding operations are carried out sequentially, followed by assembly and packaging operations. The flow of parts and assemblies occurs in a dynamic environment.

The new welding and assembly line was to be introduced into an existing plant with the objective of finding an improved allocation for the new line and redesigning the layout of the existing lines. The changes also affected the intralogistics processes. The production system is characterized by an increasing product variety, product assembly on request, and the application of lean principles (Costa et al. 2017). The problem was addressed using computer simulation, statistical analysis, and lean tools (Rohani and Zhraee 2015).

During the research it became apparent that there is a need for a methodology that integrates some of these tools into a coherent system. This is especially important when considering multiple workstations or lines and intralogistics in a lean environment. One set of tools involves layout design (Muther and Hales 2015), intralogistics organization (Meyer 2015), and lean principles (Wilson 2010). Another set of tools involves simulation modeling and experimentation.

The main goal of this paper is to define and illustrate the developed method and supporting tools for improving layout and intralogistics design and redesign using lean thinking. The approach uses cyclical processes and is defined in the context of traditional methodologies for building simulation models. The approach is illustrated via a comprehensive example.

The paper's main contribution is the definition of a new methodology for simulation modeling that is based on five foundations: (1) PFEP (Plan for Every Part), which is the main integrator, (2) workstations as the basic objects, (3) a high-level scripting language, (4) cyclical processes that enable a multimodal approach, and (5) 3D discrete-event simulation.

The paper is divided into seven sections. Following an introduction, the second section contains a literature review on layout, intralogistics, production, and assembly lines. In this section, some simulation tools are discussed and papers from the archive of the WSC (Winter Simulation Conference) are analyzed. The third section describes the motivation for the research and provides a problem statement. The proposed method is presented in Section 4 and key foundations are defined in Section 5. Section 6 focuses on the implementation of the method. The last section presents conclusions and outlines further research.

2 LITERATURE REVIEW

2.1 Layout and Intralogistics in Lean Systems

2.1.1 Systematic Layout Planning

The systematic layout planning (SLP) Design Process, developed by Richard Muther (1961) is a tool used to arrange workplaces by locating areas with high frequency and logical relationships close to each other. SLP is commonly used as a foundation for all manufacturing process design methods. This multi-step process is applicable to a wide variety of process design situations, including fully-automated production facilities and flexible manufacturing job shops. It includes designing and determining the basic flow patterns of parts and material through a process and the identification of the size of each process element and the relationships that each element shares with others in the process. The SLP process is applied to process design in both new and existing facilities and to major and minor process design activities. It is used for analyzing new products, changes in demand, changes in product design, new machines, bottlenecks, buffers, and transfer times.

A layout is the arrangement of machines and equipment within a workspace that considers the associated products, processes, and logistics as well as their relationships. The design or redesign of a layout focuses on minimizing material handling costs, investments, and throughput time while maximizing flexibility and the efficient use of space. There are two main approaches (methods): (1) having the right equipment in the right place for effective processing and (2) using the shortest distances and shortest times.

Figure 1 defines the steps proposed by Muther and Hales (2015) for implementing systematic layout planning.

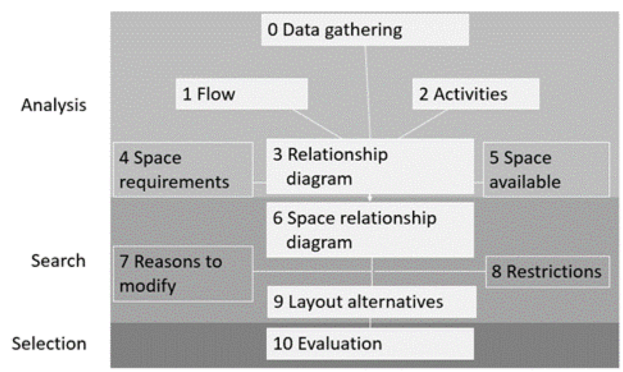


Figure 1: Systematic Layout Planning (Muther and Hales 2015).

There are several methods for plant layout design (Naik and Kallurkar 2016): systematic layout planning (SLP) (Zhu and Wang 2009), algorithms (Deb 2005), and simulation. Parveen and Ravi (2013) review metaheuristic approaches, such as: Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Tabu Search (TS). All of these are used to optimize the multi-objective layout problem. A number of studies have attempted to explore the influence of facility layout design on the operational efficiency in manufacturing (for example, Anucha et al. 2011; Pinto and Shayan 2007; Tao et al. 2012; Vaidya 2013; Yifei 2012). However, the work of Anucha et al. (2011) is descriptive, i.e., it lacks quantitative support and is largely based on intuition (Lekan et al. 2017) .

2.1.2 Milk-Runs in Intralogistics Systems

Bozer and Ciemnoczolowski (2013) describe Milk-Run systems as "route-based, cyclic material handling systems that are used widely to enable frequent and consistent deliveries of containerized parts on an as-needed basis from a central storage area (the 'supermarket') to multiple line-side deposit points on the factory floor". Meyer (2015) defines the goal of designing Milk-Run system as "the definition of cost efficient, regularly recurring transport schedules for suppliers with a regular demand". Milk-Run systems are used to achieve a number of operational benefits. While Brar and Saini (2011) and many other authors, identify these benefits, reduction in transportation costs is the most commonly mentioned benefit. The cost of a Milk-Run system primarily depends on the layout of transport routes – the routes affect the total distance travelled by logistics trains and the duration of deliveries. In order to effectively implement a Milk-Run system, its design consists of the following steps:

- Define transport routes and the Milk-Run stops on the production system layout
- Specify tuggers and trailers (types and quantities) considering the transported containers
- Design the train work organization that satisfies the demand for material that must be delivered in specific containers, in a specific quantity, and with a specified frequency.

The last two points are particularly challenging. They require determining the demand that is generated by the production system and the synchronized deliveries that are subject to a series of constraints. In order to design a transport system that is based on the Milk-Run concept, it is necessary to consider the logistics train as a set of objects that can be freely exchanged and enabled to transport the necessary number of specific containers.

2.1.3 Lean Production

Lean production is an improvement strategy that can be used to address manufacturing challenges. Lean provides a set of principles and tools that are used to gain operational efficiency, reduce process waste, and increase productivity. While the majority of the studies focus on a single aspect of lean, the successful application needs to focus on multiple aspects, such as Value Stream Mapping (VSM), Line Balancing, Single Minute Exchange of Dies (SMED), Visual Management, Production Levelling, 5Ss, LLD, etc. (Wilson 2010).

Lean Line Design (LLD) is a method for implementing such manufacturing principles as process orientation, perfect quality, standardization, flexibility, waste elimination, transparent process, associate involvement, etc. The LLD involves implementing four steps: demand analysis, operator flow design, line design, and supporting system design. Designing manual and semi-automated work systems using LLD results in a better line (Avikal et al. 2013). LLD improves output, eliminates ergonomic problems, decreases target cycle time, reduces the size of the work area, improves work flow, and integrates workstations and equipment.

Assembly line balancing includes assigning tasks to a set of workstations with consideration of constraints, a set of precedence relationships, processing time, and cycle time (ElMaraghy and ElMaraghy 2016). Line balancing is used to achieve a similar cycle time at each station (Hu et al. 2011).

Harris and Harris (2004) define five major steps for the transition from traditional material flow to lean material flow using a Milk-Run system:

1. Develop a plan for every part (PFEP).
2. Build the purchased parts market
3. Design delivery routes
4. Implement pull signals
5. Continuously improve the system

2.2 Commercial Software Analysis

There are many simulation tools that can be used for facility planning. This research considered several simulation tools and Table 1 summarizes the findings that consider the following features:

- Workstation as the basic object, where a workstation object contains: container locations, worktables, assembly stations, disassembly stations, operators (e.g., human, robot, manipulator, AGV), welding stations, and logistics trains. In the basic object, all material moves are inside.
- PFEP (Plan For Every Part), where a database (table) is an integral part of a simulation tool.
- Interactive layout – possibility to work with a part of a facility as a consistent object (see: Workstation explanation).
- Level of instruction – software programs offering a low level of instruction (level of programming language like C++, Java, Python) with a library of hundreds of functions; whereas, a high level of instructions defines real operations in a way that makes Yamazumi analysis available (Sabadka et al. 2017).
- Core 3D – many software programs are limited to two-dimensional visualization (2D), which is not easy to visualize, understand, or evaluate. Other software systems offer 2D/3D where three-dimensional visualization is available through postprocessing; however, this is only for visualization, not for direct work with 3D objects.

Table 1: Comparison of some commercial simulation tools (versions from January 2018) [* developed by Atres (2018); ** developed by Siemens (2018)].

Simulation Software	Workstation as basic object	Included PFEP	Interactive Layout	Level of Instructions	Core 3D
Anylogic	No	No	No	Low	No
Arena	No	No	No	Low	No
Emulate 3D	No	No	No	Low	Yes
ExtendSim	No	No	No	Low	No
FlexSim	No	In Progress *	No	Low	Yes
Plant Simulation	No	In Progress**	No	Low	Yes
Simio	No	No	No	Low	No
Simul8	No	No	No	Low	No
Witness	No	No	No	Low	No

2.3 WSC Paper Analysis

During our research, we have analyzed the archives of the Winter Simulation Conference, an excellent and accessible repository of simulation resources. The search focused on three main topics: layout design, intralogistics using a Milk-Run system, and PFEP. The results are summarized in Table 2. It is interesting that there are no papers that use PFEP with simulation since PFEP is a basic lean concept and is a standard tool in many assembly factories, especially in the automotive industry.

Table 2: WSC Paper Analysis.

Year	Layout Design	Intralogistics (Milk-Run)	Using PFEP
2017	2	0	0
2016	1	1	0
2015	1	0	0
2014	2	0	0
2013	3	0	0
2012	1	0	0
2011	1	0	0
2010	0	0	0
2009	1	0	0
2008	2	0	0
2007	1	1	0

3 MOTIVATION AND PROBLEM STATEMENT

This research is applied in a part production facility in the automotive industry. The production process involves several welding stations, where welding operations are carried out sequentially prior to assembly and packaging operations. The goal of the research is to organize and maintain a management system for parts, components, subassemblies, and other material that are delivered to the enterprise from suppliers and design (redesign) a logistics system that minimizes waste and ensures an effective flow of material inside the factory.

The word “flow” has a special meaning here – it can be compared to the bloodstream of a living organism. The internal logistics system, with its delivery routes, is like the cardiovascular system of an organism. There are arteries (supply routes) supplying nutrients (purchased parts) and veins – taking away contaminants (empty containers for parts), so as to keep the cells of the body (production nests) healthy and provided with what they need and when they need it. The arteries and veins of this system (supply routes) are also used to transfer signals from cells (production sockets) to the nervous system (production control department) with the level of nutrient demand (materials and purchased parts).

The research models the flow of parts, that are transported in containers, using the Milk-Run concept. Thus, the focus is on the flow of containers. Containers flow to production, in this case where welding operations are performed, from a so-called supermarket where containers are filled with parts from the warehouse. Warehouse flows are not analyzed or modeled. In assembly, items in containers or on the logistic trollies "float" to the next workstation. The process continues until items reach a buffer in front of the finished product warehouse. The assembly operations are modeled taking into account the operation time (described with the appropriate statistical distribution), disruptions (failures), and planned breaks; however, the focus is on the flow.

The factory is part of a dynamic market. The layout “lives” and changes when production lines are closed or new lines are introduced. Managers, production engineers, planners, logisticians, and lean specialists all work on changes in the the layout and intralogistics system.

The literature reveals several studies which investigate the effective design of facility planning in a production line of manufacturing processes. They search for the optimum layout configuration using general heuristic methods such as Tabu Search (TS), Simulated Annealing (SA), and Genetic Algorithms (GA). However, they are time consuming and it is difficult to get the feeling of the actual setting as well as the actual dimension of the machines and other equipment in the facility design. Simulation is a powerful tool to assess and evaluate possible configurations in a layout design. According to Beaverstock et al. (2017), simulation could be the best aid in decision making during design, analysis, and improvement of manufacturing systems. Moreover, computer simulation is used to design systems that raise productivity, improve product quality, shorten lead time, and reduce cost.

As mentioned in Section 1, it became apparent during this research that engineers in factories need a methodology that integrates layout, intralogistics, product, and process data (see Figure 1) into one consistent system. Based on the literature (Harris et al. 2003; Conrad and Rooks 2011) and this research, a methodology is developed that uses the concept of PFEP as an integrator of these into one system and links them to a core 3D simulation.

4 KEY FOUNDATIONS

In order to effectively define the proposed methodology, it is necessary to explain the following five key foundations.

The PFEP (Plan for Every Part) is used as the main integrator. PFEP is a database created to gather and maintain information about all parts, components, supplies, WIP (Work In Progress) inventories, raw materials, finished goods, and any other form material used in processes. The definitions and requirements of PFEP vary depending on specific needs and industry, but in general, PFEP fosters the accurate and controlled management of commercial information. PFEP is an essential lean tool; and, when combined with quality, delivery, true cost sourcing, value stream mapping, and supplier development initiatives, it can transform average supply-chain operations into world-class, just-in-time lean enterprises. PFEP enables organizations to plan more effectively the completion dates, true costs of parts, and production launch risks. Then, once the product is launched, PFEP is used to proactively maintain high-functioning supply-chain operations by managing and optimizing inventory costs, inbound logistics costs, and part supply change costs. Details of using PFEP for simulation modeling of production systems are explained in Pawlewski (2018a).

Since simulation is a crucial component, the choice of a simulation program as the environment that is treated as a SOS (Simulation Operating System) is the key decision. The FlexSim software was chosen because it is core 3D (working directly in a 3D environment) and it is an open system, i.e., system logic can easily be defined (Beaverstock et al. 2017). In a situation where the location of containers with parts is crucial (because of dimension Z – see Figure 2), a core 3D simulation program is the best choice. Then, the position of containers can be manipulated using a mouse or with a table that contains 3D coordinates. This software also allows a designer for building a virtual reality (VR) environment and provides the feeling of an actual setting in the factory.

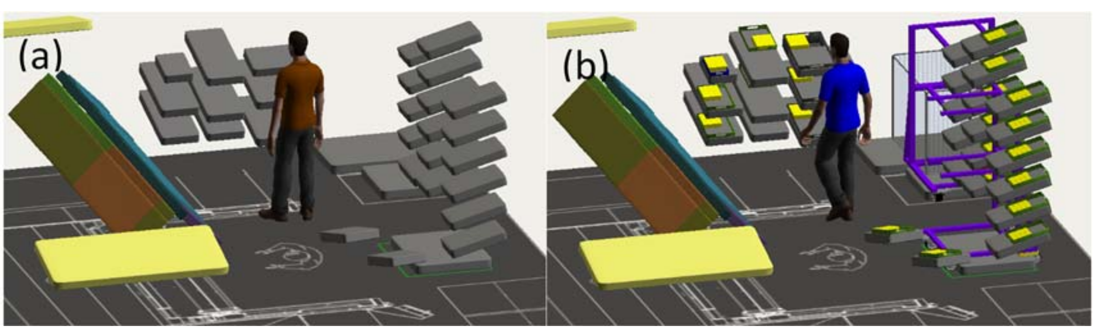


Figure 2: Locations of containers in the 3D core simulation program FlexSim.

As mentioned in Section 1, simulation programs use machines, operators, robots, etc. as basic objects. However, this level is too low for an interactive layout. This research defines the workstation as the basic object, which means that it is possible to move the whole object on the layout (Figure 3).

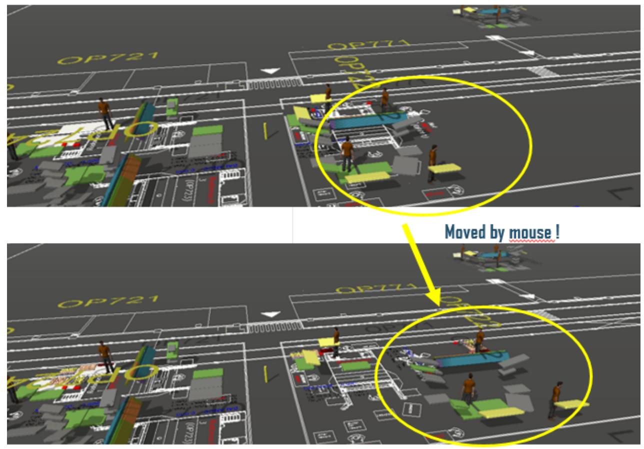


Figure 3: Screens with visualization of moving workstation by mouse.

While a workstation is treated as a basic object, it includes containers, locations, worktables, assembly stations, disassembly stations, operators (e.g., a human, robot, manipulator, AGV), welding stations, logistics trains, etc. A workstation is defined through a template; an example is shown in Figure 4. Once defined through the template, a workstation is generated automatically in the simulation model.

As mentioned above, an object which can move parts or a container of parts is called an operator. It means that Operator is a class to which the following items belong: worker (human), robot, manipulator, forklift, AGV, and conveyor. A high-level scripting language, which consists of 57 instructions, describes behaviors of operators. The following is an example of an instruction.

```
P7   LoadFromTote   5
```

It means that an operator picks five parts from a container that is located in position P7. Pawlewski (2018b) provides a detailed description of this instruction. One of the arguments to define the scripting language is to provide a Yamazumi analysis.

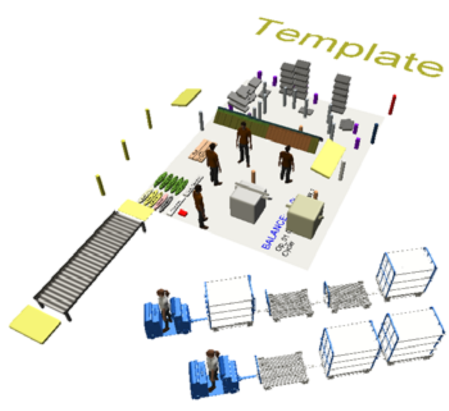
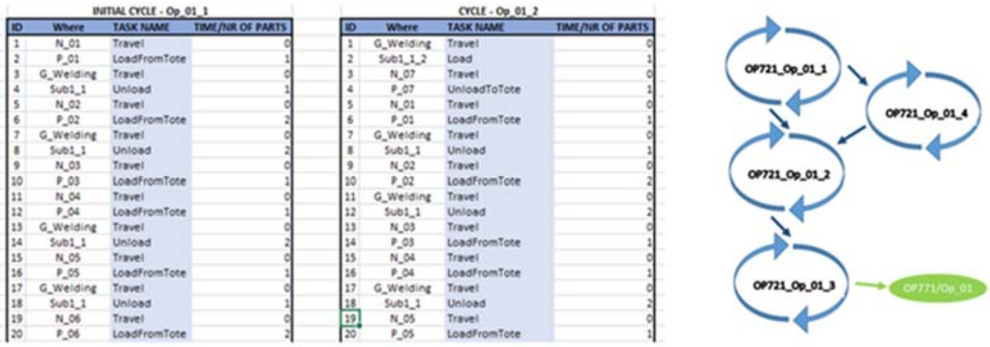


Figure 4: Template and object generated from it.

The structure of the scripting language is defined such that the instructions can be stored in tables. A multimodal approach with the use of cyclic processes is the basis for the formal construction of the scripting language. The approach is described in Bocewicz et al. (2018). An example use of the scripting language and the relationship with cycles, which describes behaviors of operators, is shown in Figure 5.



INITIAL CYCLE - Op_01_1

ID	Where	TASK NAME	TIME/NR OF PARTS
1	N_01	Travel	0
2	P_01	LoadFromTote	1
3	G_Welding	Travel	0
4	Sub1_1	Unload	1
5	N_02	Travel	0
6	P_02	LoadFromTote	2
7	G_Welding	Travel	0
8	Sub1_1	Unload	2
9	N_03	Travel	0
10	P_03	LoadFromTote	1
11	N_04	Travel	0
12	P_04	LoadFromTote	1
13	G_Welding	Travel	0
14	Sub1_1	Unload	2
15	N_05	Travel	0
16	P_05	LoadFromTote	1
17	G_Welding	Travel	0
18	Sub1_1	Unload	1
19	N_06	Travel	0
20	P_06	LoadFromTote	2

CYCLE - Op_01_2

ID	Where	TASK NAME	TIME/NR OF PARTS
1	G_Welding	Travel	0
2	Sub1_1_2	Load	1
3	N_07	Travel	0
4	P_07	UnloadToTote	1
5	N_01	Travel	0
6	P_01	LoadFromTote	1
7	G_Welding	Travel	0
8	Sub1_1	Unload	1
9	N_02	Travel	0
10	P_02	LoadFromTote	2
11	G_Welding	Travel	0
12	Sub1_1	Unload	2
13	N_03	Travel	0
14	P_03	LoadFromTote	1
15	N_04	Travel	0
16	P_04	LoadFromTote	1
17	G_Welding	Travel	0
18	Sub1_1	Unload	2
19	N_05	Travel	0
20	P_05	LoadFromTote	1

Figure 5: Example of sets of instructions stored in tables and relations between cycles which describe behaviors of operator (Pawlewski 2018c).

5 METHODOLOGY

The proposed methodology is composed of two main steps which answer the questions:

1. Step 1 – How to build a simulation model?
2. Step 2 – How to analyze and experiment with the model?

Figure 6 illustrates the methodology, which is composed of five stages: Topography, Product & Process, Linkages, Simulation, and Results. The first three stages can be performed simultaneously.

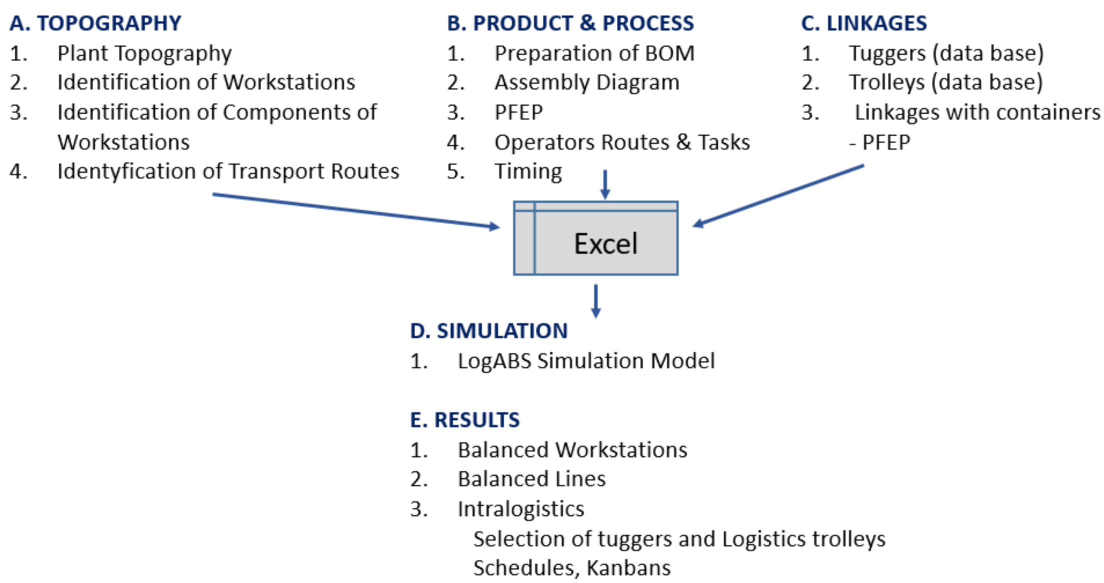


Figure 6: Structure of methodology.

The Topography stage is used to collect data about objects which form the layout. The following types of objects are recognized: locations of workstations, locations of components of workstations (such as operators, worktables, assembly stations, disassembly stations, and welding stations), and transport routes including bus stops, curves, intersections, straight sections, one-way and two-way roads. Data about these objects form a database. Rules for naming the objects and saving geometric data are defined.

The Product & Process stage is used to collect data about products and processes. Data about BOM (Bill of Materials) and PFEP (Plan For Every Part) are collected in Excel tables according to a set of defined rules. Detailed knowledge about a BOM is necessary to build a proper PFEP. Data about processes are also formed in tables (in Excel) by defining Operator Routes and Tasks using the developed scripting language and assembly diagrams. Many tasks are defined by duration. Thus, data about timing are also necessary. Times can be identified using statistical distributions.

The Linkages stage is necessary to build logistics trains (for Milk-Runs). To do this, a list of possible sets of tuggers and trolleys and linkages to PFEP is needed. Based on this, containers with parts can be assigned to particular trolleys. These data are collected into tables in Excel.

The result of the first three stages is an Excel file where all data necessary to build a simulation model are saved. Based on Excel templates, these stages can be performed by engineers from the factory who do not need to be versed in simulation. All of the data are available in a factory, but are distributed in different places and used by different people.

The simulation model of workstations is generated automatically based on the Excel data. Figure 7 presents four levels of the manufacturing system analysis and modeling. Level 0 is formed by resources from a simulation program (SOS) – they are generated automatically using a template (Figure 4). Modeling and analysis are performed from the bottom to the top – starting with level 1, then level 2 and ending with level 3. Table 3 summarizes what data are necessary as input for each level and which results are achieved.

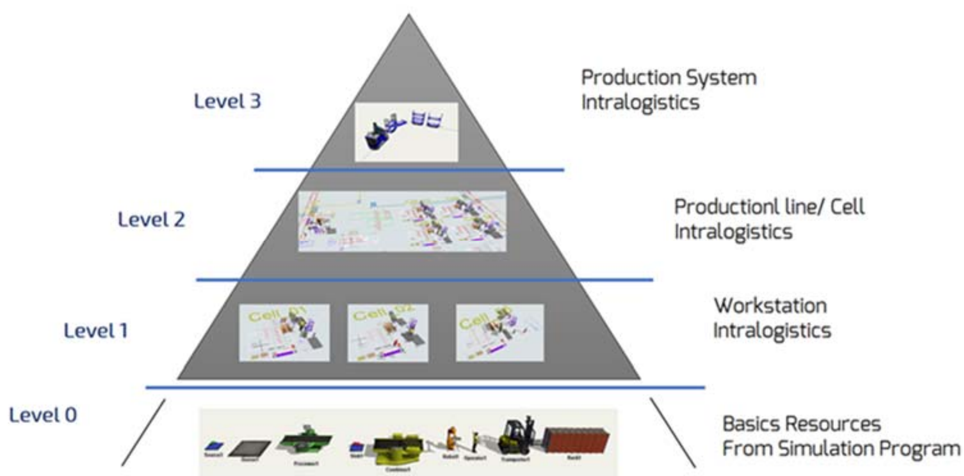


Figure 7: Four levels of manufacturing system analysis and modeling.

Table 3: Three levels of analysis – inputs and results.

Level	Input	Results
1	Layout with first positions of parts, BOM, operations of operator, welding time, Takt time, loading/unloading time, operator speed, acceleration, deceleration, welder structure	Basic statistics, visualization in 3D, possibility for optimization of operator's movements, good positions of totes with parts
2	High-quality cells, cell connections, logic, production program	Balanced line, visualization in 3D
3	High-quality line, production program, warehouse position, intralogistics concept, KPI's, objective function, decision variables	Optimized intralogistics, selection of tuggers and trolleys, Milk-Run schedules, visualization in 3D

6 IMPLEMENTATION

The methodology is implemented using two tools: Excel for stages A, B, and C, and the LogABS tool embedded in FlexSim for stages D and E. As mentioned earlier (Section 4), FlexSim is chosen as the simulation environment (SOS – Simulation Operating System). LogABS contains a high-level script interpreter, a database to save data from Excel, a template of the basic object (i.e., a workstation), a mechanism to automatically generate workstations, special resources (assembly station, disassembly station, welding station, tugger, trolley, container etc.), Windows interface for users, and a result chart generator including Yamazumi analysis (Figure 8). Figure 9 shows the information flow in the process of building a simulation model.

Figure 8: Yamazumi charts and operators load, distance, and time charts generated in LogABS.

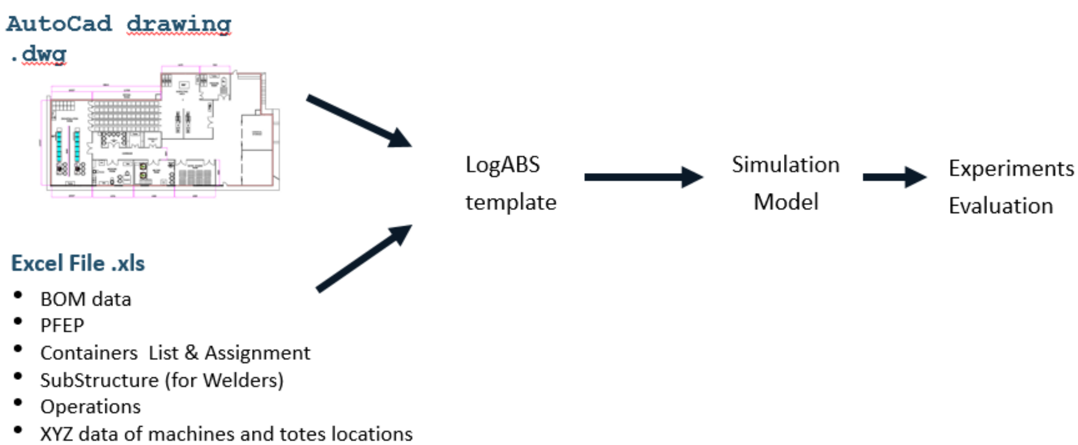


Figure 9: Information flow during the building the simulation model.

7 CONCLUSIONS AND FURTHER WORK

This paper defines a methodology for layout and intralogistics design. The developed methodology is based on the production and supply of components for automotive manufacturers. However, this methodology is currently being applied in the furniture, automotive and electronics industries (four cases). The reactions from industry are promising. The methodology is being extended to include collision-free and deadlock-free implementation of intralogistics processes. Again, the overall goal of the research is to prepare a tool that can help engineers to quickly and optimally react to demands from the market. It is interesting to combine the basic heuristic methods with a 3D simulation technique for evaluating the existing layout and intralogistics arrangement.

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AUTHOR BIOGRAPHIES

PAWEL PAWLEWSKI is Professor of the Faculty of Engineering Management at Poznan University of Technology in Poland. He is the Managing Director of SOCILAPP - Simulation and Optimization Center in Logistic and Production Processes. His research interests include discrete-event simulation, agent-based simulation, and their applications service systems, transportation networks, and manufacturing. He has published over 120 papers. He is member of the board of Atres Intralogistics. His e-mail address is pawel.pawlewski@put.poznan.pl.