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Digital support for rules and regulations when planning and designing factory layouts

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Abstract

Factory layouts are frequently planned and designed in virtual environments, based on the experience of the layout planner. This planning and design process depends on information from several cross-disciplinary activities performed by several functions and experts, e.g., product development, manufacturing process planning, resource descriptions, ergonomics, and safety. Additionally, the layout planner also needs to consider applicable rules and regulations. This experience-based and manual approach to plan and design factory layouts, considering a multitude of inputs and parameters, is a cumbersome iterative process with a high risk of human error and faulty inputs and updates. The general trend in industry is to automate and assist users with their tasks and activities, deriving from concepts such as Industry 4.0 and Industry 5.0. This paper presents and demonstrates how digital support for rules and regulations can assist layout planners in factory layout work. The objective is to support the layout planner in accounting for area/volume reservations required to comply with rules and regulations for workers and equipment in the factory layout. This is a step in a wider initiative to provide enhanced digital support to layout planners, making the layout planning and design process more objective and efficient, and bridge gaps between cross-disciplinary planning and design activities.

Keywords: Factory layout; digital support; Industry 5.0; rules and regulations

1. Introduction

The planning and design process of the factory layout is today frequently performed with computer-aided technology applications (CAx) [1]. The virtual environment representing the factory layout is used to consider several aspects and requirements from several stakeholders. The modern IT landscape is diverse in the sense that different software tools provide different capabilities and functionalities in order to perform the various planning and design activities, meaning that often quite a few software applications are in use in the manufacturing planning and design process [2]. The ability of CAx applications is continuously evolving, and they are considered to be a crucial part in the future for reducing the development time and cost of manufacturing processes and factory setups [3].

The phases of a factory layout can often be exemplified by location, general overall layout, detailed layout plans, and

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installation phase, and the factory layout depends on inputs from several activities such as product development, manufacturing process development/planning, and tests of feasibility (e.g., collision detection and ergonomics) [4]. In the factory layout work and its different planning phases both block layouts (for area/volume reservations) and detailed layouts are generated. The block layout is created early in a project to reserve area/volume needs of the factory project. The more descriptive the block layout is, the more effective the project will be in defining possible available area for the detailed factory layout and its intended processes and resources in the next planning steps. The detailed layout defines the spatial positions of geometrical descriptions of artifacts such as resources, equipment, and products. Together this describes the setup of a factory, typically done in virtual environments [5]. Since this planning most frequently is based on the experience of the layout planner, the area/volume claim reservations depend on the layout planner's expertise in the regulation requirements for the block layout definition. Hence the way of working today to generate the block layout is subjective. During the lifecycle of the manufacturing factory, the virtual factory layout is a "living" document that constantly needs to be kept up to date, so that analyses, verifications, and simulations on, e.g., new product or resource introductions can be carried out [6].

1.1. Consideration of rules and guidelines

In a factory it is not only the actual intended processes, products, and equipment that need to claim area/volume reservations. In order to be able to produce inside a factory, there also need to be area/volume reservations for staff and passive and active equipment and their movements, in order to operate and perform the tasks to realize the product and manufacturing process, [7], e.g., to carry out maintenance tasks, and to operate active equipment such as forklifts to supply the manufacturing process material façade [4]. The area/volume claims in a factory are typically defined with guidelines relating to law and regulation documents [4]. Hence, the activity is dependent on the fact that the layout planner is aware of and plans according to applicable guidelines and regulations [8].

At many companies, knowledge of rules and regulations is linked to certain expert roles and planning activities [2]. The current way of working then depends on the layout planner having either expert knowledge of the rules and regulations to follow for the activity in question or awareness of where to find the relevant documentation of such knowledge or which expert has this knowledge. Such experience-based way of working easily leads to a layout planning and design process that is slow and prone to mistakes and misunderstandings.

1.2. Challenges

The digitalization process to connect and enable information exchange seamlessly between applications, functions, and experts is an ongoing journey for many companies, where a general trend is to try to automate and assist activities that are usually carried out more or less isolated [9]. The current way of working with factory layout work highlights that there is a need to assist the layout planner when generating information such as area/volume claims for safety, rules, and regulations.

One of the main points of Industry 5.0 is that humans and machines are to work cooperatively and in symbiosis with each other in the workshop [10], where humans are assisted by robots and machines in performing repetitive and heavy tasks and are rather able to focus on more complex tasks such as those requiring great dexterity, human touch, and cognitive skills of the human craftsperson. Industry 5.0 then extends from previous digitalization concepts such as Industry 4.0 [11]. Analogously, it is important to also support layout planners in the layout planning and design process, so that they can perform their tasks more efficiently and with lower risks of mistakes and misunderstandings.

The aim with this paper is to present and demonstrate how rules and regulations connected to resources and equipment in the virtual environment can be added to assist layout planners when performing factory layout work. The objective is then to showcase digital support for layout planners in executing the associated tasks correctly, efficiently, and objectively, with the performance to a lesser degree depending on the background and experience of the layout planner.

2. Method

The methodological approach of this research follows the design science research concept [12]. This approach allows for gathering descriptions of issues from end users, in this case factory layout planners, and then generating and evaluating potential solutions to the issues through the creation of artifacts, e.g., a software or demonstrator. Information on issues regarding the consideration of rules and regulations in the current layout planning and design process was gathered through observations and semi-structured interviews with stakeholders in industry consisting of layout planners, experts, and other planning staff.

2.1. Virtual environment for demonstrators

The software Industrial Path Solutions (IPS) was used to create demonstrators. IPS is a math-based software tool used for simulations of digital test assemblies with rigid body path planning [13], flexible components [13], ergonomics simulations [14], optimization of robot and multi-robot stations [15], and surface treatment processes [16]. IPS has an application programming interface (API) for the Lua scripting language, which is an open-source lightweight scripting language [17].

CAD models of resources, products, and equipment were created in Dassault CATIA V5 and AutoCAD Architecture 2022. The virtual descriptions were exported and converted for IPS import.

2.2. Demonstrator 1 – Block layout creation (assembly)

The block layout for an assembly process should account for area/volume reservations for intended product, manufacturing process, and resources, including staff to assemble the product. A demonstrator assisting layout planners in generating block layouts for assembly processes was created. The process description used to demonstrate the block layout creation is a pedal car assembly process in use at Scania Smart Factory Lab.

With selected geometries in the IPS scene (Step 1), a Lua script starts to generate a block layout in an automated manner with options to consider for the software tool user.

The Lua script (Step 2) defines a bounding box to represent the space claim needed of the selected geometry. In Step 3, options to claim operator workspace are presented, with choices of in front and/or rear of the selected geometry. With the option selection, space reservation is created following a predefined regulation, in this case AFS 2020:1 [18], stating minimum width, length, and height requirements of 800 mm x 1000 mm x 2100 mm, respectively, for operator workspace. Optionally the software tool user can fill in customized values for the dimensions with the interface of the Lua script. The script series continues with Step 4 to ask the software tool user whether operator workspace is required on both left and right side, on only one of the sides, or not at all. Based on the selection, the workspace reservation is added automatically to the digital object. The script series Step 5 presents the option to add a *forcing step* for the operator (a forcing step is a company-specific space reservation to achieve a better work environment by causing operators to actively lift their feet from the floor rather than stand still and rotate their waist on the same spot). If a forcing step is selected, an area reservation is added with the predefined width of 200 mm (alternatively the parameter can be set manually). Then with Step 6, the option of material façade reservation is given with the pre-set values for the width of 1500 mm (the parameter can be set manually).

Finally, Step 7 gives the option to set aisle reservation for the block layout. If needed, the software tool user can then add aisles according to the SS-EN ISO 3691-4:2020 [19]. The Lua script offers options such as single- or double-directed aisles. The script then further presents options regarding what kinds of resources are to be used in the aisle, e.g., forklifts or driverless vehicles, and the software tool user needs to input the width of the resource. The schematic proceeding of Steps 1–7 is shown in Fig. 1, and an example of the execution is presented with an online animation at http://vimeo.com/748715972.

2.3. Demonstrator 2 – Safety distance for active equipment

Demonstrator 2 showcases how the creation of constraints for selected geometries can be automated by adding safety distances around active equipment (in this case a tugger train, Fig. 2). This assists the layout planner in considering and validating these requirements when planning and designing the factory layout. The software tool user can select a geometry, and then the script automatically defines a bounding box to represent the space claim of the selected geometry (in blue in Fig. 2). Next, the script gives the user the option to add a safety distance on selected sides of the blue bounding box. The user can select from predefined values, or fill in any value, to claim area in regard to regulation requirements (in yellow in Fig. 2).

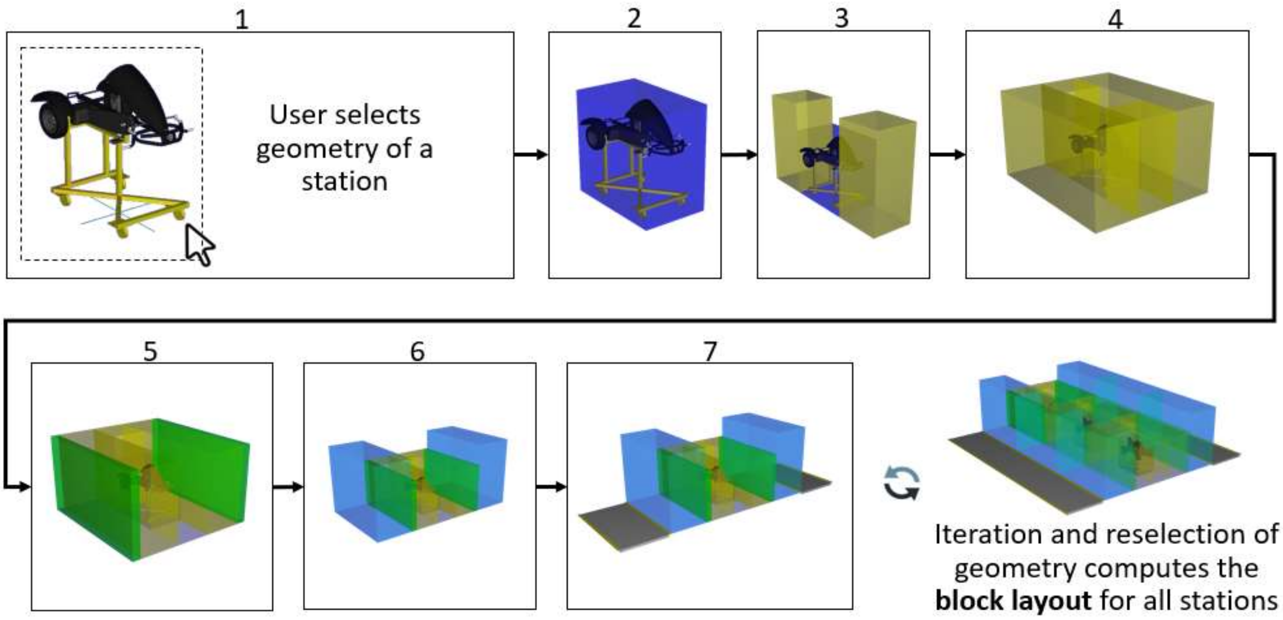

Fig. 1. Digital support to generate the block layout based on selected geometries.

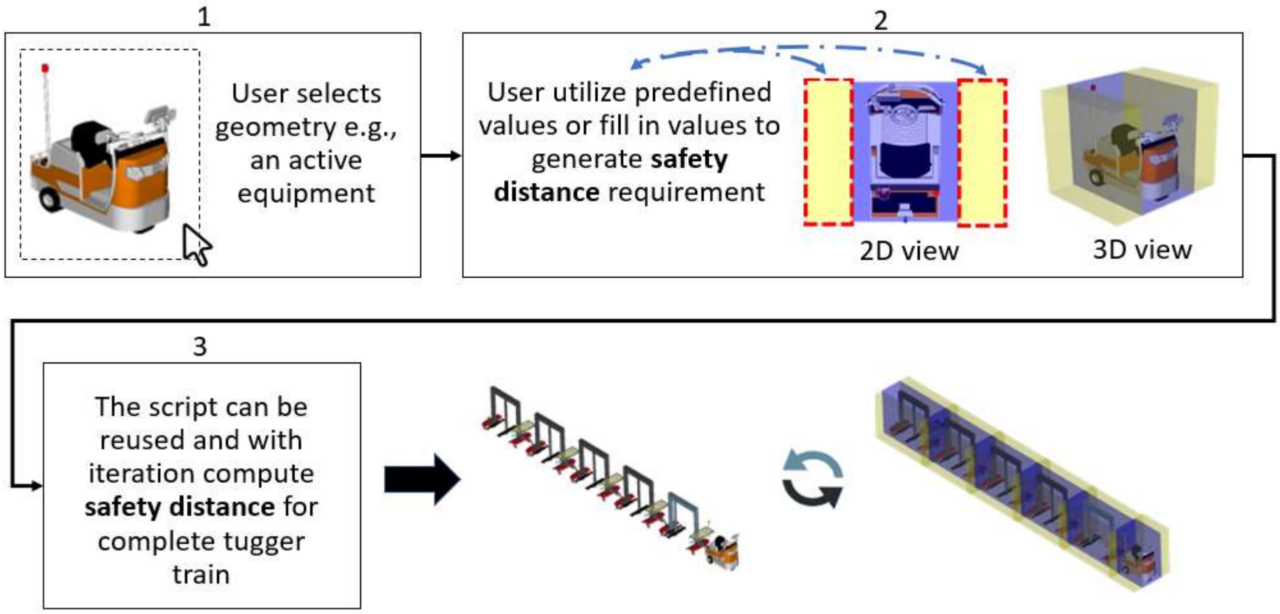

Fig. 2. Digital support to create safety distance onto selected geometries.

3. Results

The demonstrators showcase how smart solutions in digital tools can assist layout planners in considering rules and regulations in a more correct, efficient, and objective manner when carrying out factory layout work. The demonstrators present how predefined or user defined dimensions can be added to passive (Demonstrator 1) or active (Demonstrator 2) equipment in the factory layout. The dimensions are based on different rules and regulations, and facilitates the software tool user to access and consider different standards, rules and regulations applicable for layout planning and design.

3.1. Demonstrator 1 – Block layout usage (assembly)

Demonstrator 1 illustrates how regulations and requirements can be considered in a standardized way in the layout planning and design process. With scripts, guidance is provided with options for the layout planner to generate a block layout according to applicable industrial regulations (Fig. 1). The scripts are generic in the sense that they create the block layout based on user-selected geometries in the scene, i.e., the scripts can be used for all kinds of geometrical selections to assist the creation of a block layout. The generated block layout can then be used as a basis for subsequent phases in the factory layout process, e.g., the planning and design of a detailed layout (Fig. 3).

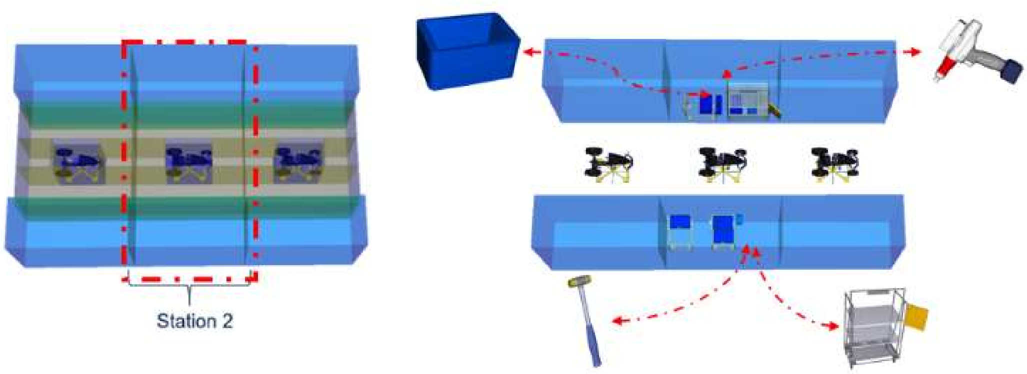

Fig. 3. Usage of the generated block layout (left) to plan and design the detailed layout (right).

3.2. Demonstrator 2 – Safety distance for active equipment

Demonstrator 2 illustrates how a digital support tool can provide the layout planner with guidance to create area/volume reservations for safety distances around active equipment. With the sweep volume functionality in IPS, the entire space claim of the complete path can be generated. The demonstrator is presented with an online animation at https://vimeo.com/668233686.

The functionality of the script used in the demonstrator goes further than just the tugger train example presented. The script is generic in the sense it generates custom sized volumes onto any user-selected geometry in the scene based on given input, i.e., the script can be used for all kinds of geometrical representations to automatically create distances around passive and active equipment. Additional usage examples are presented with online animations at:

- https://vimeo.com/748717761
- https://vimeo.com/748718243

4. Discussion

The approach to provide digital support in the software tools used to plan and design manufacturing and factory layout work is promising, and the strategy is consistent with the general trend in Industry 4.0 and Industry 5.0 to automate and assist the human with tasks and smart solutions for decision making.

4.1. Layout work

The demonstrators show how digital support in software tools can provide layout planners with guidance and assistance to account for rules and regulations in an automated manner in the layout planning and design process. This is believed to assist layout planners in executing the associated tasks correctly and objectively, with the performance to a lesser degree depending on the background and experience of the layout planner, hence leading to a more efficient process, less prone to mistakes and misunderstandings. When regulations are updated, the scripts of the demonstrators can be modified, and all users will have access to the same requirements.

During the phases of factory layout work, the objects that are positioned and planned in the factory layout will be re-described several times and supplemented with new information continuously. In addition to the actual defined geometries there also needs to be area/volume reservation accounted for around the geometries, e.g., for operator workplaces around the equipment and area/volume reservations in front of electrical cabinets and machine doors so that the doors can be opened. All changes of the resource descriptions and area/volumes need to be considered in the context of the factory layout to ensure a safe and productive factory. Therefore, it is important to keep the virtual factory layout up to date so that analyses and simulations can be performed on accurate datasets and allow for digital support to make sure that also the rules and regulations are considered at each update. The more descriptive the factory layout is in each phase of a project, the more accurate the project will be in defining possible solutions.

Modern software tools allow to use the actual models and blueprints of the resource that is to be set up in the intended factory. The 3D environment of these descriptions can be utilized to run simulation and analysed before the investment or installation happens. However, the design of the factory layout work is based on the software tool user's experience and knowledge of what needs to be accounted for in the factory layout work, e.g., in regard to rules and regulations. With the demonstrators of this paper, it is shown that a layout planner can get guidance and assistance to account for rules and regulations in an automated manner.

4.2. Consideration of results and future research

Factory layout work is today described and planned with virtual environments. The planning is most often done based on experience of an engineer, and the factory layout depends on several different inputs made and planned with separate software tools. Although the dependencies are cross-disciplinary, the data information created in one activity is often distributed manually as input to other activities. Rules, regulations, and requirements needs to be considered in a standardized way making the layout planning and design process more objective and efficient as well as integrated and consistent with other related planning and design activities undertaken at a company.

Also, with digital support, area/volume reservations can be created and illustrated fast and iteratively. Having such assistance when performing area/volume reservations gives the software tool user a start-off point for cross-disciplinary discussions. This is believed to enable better common understanding among stakeholders and facilitate faster decisions in discussions on the need of certain area/volume requirements.

Worth pointing out is that this paper aims to demonstrate conceptual solutions and does not claim that the software tool used to create the demonstrators is the only plausible solution; rather, it is expected that similar approaches can be realized with other software tools and programming languages.

Continued efforts will be made to identify and add more rules and regulations to the digital support tool, to further enhance the support in providing efficient and objective assistance to layout planners. Structured evaluations with intended users will later be carried out to assess the usability of the digital support.

5. Conclusion

Decisions made in regard to the factory layout affect several cross-disciplinary planning activities and set the foundation of the production potential, hence having a strong impact on parallel and subsequent activities. The paper presents digital support to facilitate easy access to rules and regulations when planning and designing the factory layouts. This is believed to provide risk mitigation and contribute to early project completion and projects with less costly retrospective engineering.

By the means of two demonstrators, the paper presents how information embedded in digital support in software tools can assist layout planners to consider rules and regulations efficiently and objectively in the factory layout planning and design process. This is a step in line with Industry 4.0 and Industry 5.0, i.e., to automate and assist the human with tasks and smart solutions for decision making.

The results are promising in the sense that area/volume claims can be available fast and easily, and by that support the work of the layout planner and trigger and enrich discussions with other stakeholders on issues that relate to the factory layout. The approach presents a smart way to assist layout planners in efficiently and objectively executing several steps in the layout planning and design process.

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