Software Evaluation Criteria for Rapid Factory Layout Planning, Design and Simulation

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Abstract

The objective of this paper is to specify functional requirements on software for rapid factory planning and design in a digital factory context. In comparison with other studies that focus on particular aspects of layout development, this work deploys a comprehensive approach, based on industrial needs, to determine main functionalities for factory layout software. The research considers integration of different layouts where original equipment manufacturer and other stakeholders involved in factory layout design collaborate with each other to develop, or extend a factory. Therefore; engineering change management and data exchange in a system neutral format are taken into account as main pillars.

Keywords: Factory layout design; Digital factory; Digital manufacturing; Software tools; Computer Aided Design (CAD)

1. Introduction

Factory layout design is a multidisciplinary, knowledge-intensive task that is of a vital issue to the survival of manufacturers in today’s globally competitive environment. The need to design and construct a new factory layout or reconfigure the current one has increased largely because of the fast changes in customer demand both from product quantity and product variety aspects. This requires companies to be more agile to plan, design and reconfigure the factory layout to be able to introduce new products to market and keep their competitive strength [1][2][3]. A well designed factory layout provides the fundament for a profitable production. Designing a factory means designing a system comprised of components of various kinds - such as building, machinery, foundation, media (ventilation, electricity, and plumbing) and material handling equipment - developed by different stakeholders. These stakeholders have different views of the layout; they typically belong to various organizations and often use different software. Further, the movement of installed equipment is often difficult due to the high degree of interdependency between various parts. Thus, layout design is a highly collaborative activity which requires combining different perspectives, considering stringent geometrical and functional constraints, interdependencies and requirements.

Digital factory and digital manufacturing has been introduced to support companies in this domain. There are different definitions for digital factory. Kjellberg [4] defines digital factory as a generic digitized model of a factory with its manufacturing system model. Wiendahl [5] expresses that digital factory or virtual factory must be explained by its characteristics such as 3D visualization, interaction, immersion and real time data manipulation. Kjellberg declares “Digital manufacturing” as: digital manufacturing is performed in digital factory in order to verify and optimize manufacturing of real products. However; creating a digital factory in order to facilitate and support the process of factory layout design without software tools is impossible. Software tools play significant role in this area. Not only the ability of quickly and easily designing and modifying the layout but also the collaborative nature of layout design must be considered where all parties must be able to visualize, talk and share information in order to take advantage of the concepts of digital factory [6].
2. The layout Process And Needs In General

In general, the goal of the layout process is to place the equipment in such a way that it enables an efficient material flow for the intended product families and volumes. It has to be secured that the equipment fit in the building – meeting constraints on space, foundation and surrounding areas, laws and legislations concerning ergonomics or safety e.g. regulations on distance between truck corridors and operator work area has to be met, and it has to be made sure that the layout is easy to work with, that is fulfills operators’ needs.

The layout development process is typically divided into a conceptual phase and a detailed phase. In the conceptual phase, a block layout is created to show the production flow and to place different areas such as operator working area, heavy machining area or transport corridors, according to constraints between them e.g. “it should be possible to reach the machines material interface from the truck corridor”. Functional interfaces between production equipment, media, material flow and building should ideally be identified here in order to e.g. dimension the media according to the total needs of the machines.

In the detailed layout design phase, physical connections and models of each system are evolving to become more and more exact and detailed. When they are placed and verified with each other, interdependencies between different equipment geometry, or between function and geometry, show up and have to be resolved. e.g. a detailed model of a standard machine shows that with the suggested layout, the operator would have to walk an unnecessarily long distance between different machines and to optimize the operator time, the machine has to be rotated, which in turn leads to a collision with surrounding equipment which has to be replaced.

Finally, when the design of the layout is ready for implementation, the construction of the building and installation of equipment needs to be planned and coordinated in detail to enable an efficient and safe implementation.

3. Required Functionalities of Collaborative Layout Design Software

The following requirements and functionalities have been identified based on industrial needs and new methods for collaborative layout design.

According to the needs, a layout system has to support the creation, verification and modification of a layout model which is composed of many interrelated parts and developed in collaboration between many stakeholders. The system should be a collaboration environment that can coordinate different layouts developed by different disciplines and exchange and manage information and models from different sources. The functions and constraints are in this specification divided into the following areas:

- Creation of layout models
- Coordination of various models
- Management of change and logistics
- Verification of layout
- Efficiency, usability and extendibility constraints

3.1. Creation of layout geometry model

Different layout models are designed by different disciplines. The types of layout models can vary based on the nature of industry but mainly include Block layout, Building layout, Machinery layout, Foundation layout, Media layout (Ventilation, Heating, Plumbing and electricity).

2D design – modeling in 2D might be considered an old technology, with the main purpose today of enabling reuse of existing layout in industry. But 2D still has advantages since it:

- Provides a good top-view, focusing only on the details of the floor layout, of primary interest to the layout.
- 2D has established drawing annotations of distances and dimensions, envelopes of doors, and coordinate lines of the floor plan, yet to be developed in 3D.
- Is easy to print out, supporting collaboration through a common view of a large layout to many viewers when large digital visualization viewing is not available.

3D design: The digital layout design process is based on 3D digital models [7, 8]. The goal with designing a 3D digital factory layout is to accelerate the layout design process and provide the design team with rapid layout design and simulation which can enhance the factory design and construction and shorten the time to design a new layout or reconfigure it.

Integration of 2d and 3D models: This functionality enables users editing in one model with the changes being reflected in the other corresponding models.

- 3D is more efficient for layout where third dimension is important, e.g. interrelating the height of equipment with height of doors or ceiling of the building, insuring that machine is not too high or that media will fit between machines and ceilings.
- 3D visualization supports verifications based on a human perception, e.g. seeing those components are too close to each other.

Libraries of 3D parameterized models with properties: Many manufacturing facilities in a factory are standard equipment including conveyors, safety equipment etc. This implies that having a rich library of 3D digital models of standard equipment, with inbuilt attributes such as supplier name, type and variant, can accelerate the layout design process. Moreover, the
software should allow users to modify the attributes of the models based on their own design requirements, either through parametric modeling or by defining values one by one (e.g. to existing building).

Customization of models: It should be possible to customize and add properties to the models. There are several reasons to add or modify layout models. For example a machine model that is provided by the supplier does not necessarily represent the location and size of the connectors or the footprint of a machine needs to be reduced to be fitted in the available space.

Machine tools are significant parts of all manufacturing factories [7]. Capability to add and modify data about the machines subsystems such as electrical cabinet or process fluid handling is important for layout design since such data serve as a basis for decision making to media layout designers. Digital representation of mechanical, electrical and plumbing information of facilities can support the integrated collaborative layout design based on a lifecycle design approach. It serves as a shared knowledge resource for information about a facility and forms a reliable basis for decisions during the lifecycle of a layout. Further; decoupling these data from the 3D model expedites the process since there are many machine models with a similar geometry that only differ concerning the media.

Today, some commercial software can represent these kinds of data and export them in XML or HTML format. While this is an export of properties, this cannot fully solve the interoperability and extensibility issues since the interoperability depends on how the different software and users define contents of a data models.

3.2. Coordination of various models

Consolidation and integration of different models is one of the most important tasks in layout design since different stakeholders utilize different CAx systems based on their specific domains. Building, media, machine models often come from different system vendors, therefore it is essential that the layout software can support different file formats. Today the most widely used file formats in industry include vendor specific formats such as AutoCAD (.dwg), CATIA V4 (.model, .exp, .session), STP, etc.

Integrating layouts from various viewpoints: It must be possible to integrate different layout objects to visualize and analyze the overall layout. By importing robot models form outside suppliers or combining the relevant parts of another layout with your own. It must be capable of exporting necessary information to other applications for further analysis such as layout verification [10, 11].

Ability to combine and interrelate layout from various perspectives/detailing levels within one system, here it is crucial coordinate the individual systems of each model to secure that the parts are placed correctly with respect to the whole geometry.

3.3. Management of access, change and logistics

Design and development of a factory layout is a gradual process. As one stakeholder modifies a corresponding layout this affects layouts designed by other disciplines and it should be secured that this change is managed. For example one problem today is that during the installation phase is a bit unsecure because changes in one model may not reach all involved parties (a change in placement of a machine tool may affect the foundation drawing, may affect the piping or ventilation or electrical main installations in ceiling and so on). Thus Product Life cycle management (PLM) functions are needed such as:

- Versioning models, annotate models with version number and status (draft, review, release etc.).
- Ability for different parties involved in layout design to access models and data belonging to another organization. For instance media layout designers could see the machinery layout to identify and decide electrical requirements.
- Change Management – manage changes in the models of the different stage holders to make sure that the right models are combined. Access to the right version of layout components from various sources.
- Track related changes and modifications in other models and be able to assess whether that change requires a change in other models.
- A specific utilization of the versioning system for the purpose of supporting project management.

3.4. Verification

There are various aspects of the layout that need to be verified such as verifying feet, productivity, working condition, safety and ergonomics.

- Fit-checking if components collide through viewing or through automatic checking of the geometry model.
- Checking requirements on safety and ergonomics through if-then rule bases.
- Working condition through immersion.
- Productivity through material flow analysis.
- Ergonomics through immersion in the layout model or manikins with load analysis.

Clash detection: One important simulation in collaborative layout design is collision detection [8]. In a layout design the spaces common among different actors and every discipline designs its own layout in parallel. As a result in detail design phase, collision between
different models is on avoidable. Therefore clash detection functionality is important. This functionality should not only present collision among objects but also report set of intersecting points. In addition; it must allow analysts to select type of collisions to be detected (clearance, hard collision, etc.), tolerances and rules. Figure 1 demonstrates a clash detection simulation between ventilation layout and structure layout to identify the collisions and results shows the ventilation pipe that collides with the roof beam.

Figure 1. Clash detection simulation

Walk through and real time interaction with integrated layout: An important functionality for verifying the layout is the ability to walk through the layout and get a real impression of the models. Moreover the users could be able to move and manipulate the digital models changes. Real-time ray tracing for photo realistic rendering can also help designers to make the models more realistic.

Presentation and verification of model property: Presentation data in layout design context means illustrating 3D annotation (text) and dimensions and material specification. Presentation data is presented for human consumption. It is visible data, presented as notes, dimensions and tolerances, surface texture, symbols, etc. Figure 2 shows a model where the user can walk through and measure the distance between two machines in a real time and decide about the location of the new machine.

Figure 2. Walk through and measurement and adding comments in layout

Material flow simulation: Material flow simulation supports verification of productivity of material flow for different products. Material flow efficiency can be evaluated in terms of total transportation cost, capacity, machine utilization, energy consumption etc. Therefore an import functionality of layout design software is the capability of flow simulation. Moreover user interaction is a key issue in the simulation. Designers must be able to access the workstations, 3D machine models and change their location in order to assess different scenarios. Figure 3 represents a 2D layout model that designers can easily identify product routing, and various costs and analyze the efficiency of different arrangement of workstations, machines etc.

Figure 3. Material simulation

5D simulation: Simulating layout construction planning showing how the layout and its cost evolve through time (5D simulation) can clarify and give a good image about the construction activities sequence and spatial arrangement before starting the construction phase. Moreover during the layout construction, team members need to understand the progress of a project compare to their plan. This is traditionally done by using project management documents such as Gantt chart. However it is a difficult task to understand all the details due to the complexity of the factory layouts. This implies the joining the 3D visualization of the project with the planning document can prevent misunderstanding among different members, increasing comprehension and intuitive of designers about physical progress of layout and identify errors in process sequence and spatial arrangement of the layout planning process. Figure 4 represents such a model. Users can travel in time to see the planning and real time progress of the layout construction.

Figure 4. 5D simulation of layout planning
3.5. Efficiency, usability and extendibility constraint

1. Ease of use- production designers are typically not CAD-experts, but they would still like to be able to modify mechanical models.
2. Efficiency-Since layout models are often very large, comprised by many sub-models, it is crucial to make the individual models small and only include the level of detail needed for layout purposes and viewpoints(LOD). Importing models with the high level of detail in a layout results in a model with irrelevant level of detail and a large file size that is problematic to visualize and manipulate the whole model. Hence these models must be adapted for the purpose of layout design. Manually simplification of the models is a laborious and time consuming task, therefore another important functionality of a layout software, in practice, is simplification ability. Such functionality allows users to simplify a model by deciding the size range or scale of components that are desired to be visualized. However, there must be an agreement of level of detail to avoid mistakes.
3. Extensibility: Open software should enable interaction with, an extension of, the software through an open application programming interface (API).

4. Functional Requirements On Software Tools For Factory Planning and Design

This section summarizes the previously described needs in factory layout planning and design. Our requirements focus on the desired functionality and on needed information contents, omitting detailed requirements on system implementation and performance.

4.1. Create layout geometry

1. Create and modify 2D layout: create and arrange areas on a plane, modify arrangement e.g. move around areas.
2. Create and modify 3D layout: create and arrange 3D-blocks; create or import 3D models from other systems; simplify 3D geometry models if needed; modify 3D models e.g. by changing parameters; reposition and rotate 3D-models.
3. Interrelate 2D and 3D models such that changes are updated automatically in both models.

4.2. Define features, dimensions and constraints and tolerances – numeric and qualitative

4. Define and present geometric dimensions such as the width of an area or a distance between two areas.
5. Define constraints on dimensions, such as that a width should be of a certain size or that the distance between two areas should be over a certain value.
6. Define qualitative constraints on a layout – whether “necessary” or “not important” for two areas to be “close” to each other.
7. Define interfaces between different models such as the surface of a machine that should stand on the floor (landing surface) or placement of connectors, or insertion points – the location in a machine where a product should be located during manufacturing.
8. Define requirements such as safety regulations.

4.3. Add non geometrical information

9. Annotate objects (2D areas or 3D objects) with notes, for instance; name and type of the layout area.
10. Define and add non geometrical information in the factory resource models, such as technical data, cost, weight, Mean Time between Failure (MTBF), Mean Time to Repair (MTTR).

4.4 Provide libraries of components

11. Provide an internal library with 3D models of factory resources, preferably parameterized, which can be added to the layout.
12. Create and add new resources to the library.
13. Provide data base of standard mechanical, electrical and plumbing devices (MEP), provide ability to modify MEP-information and to connect MEP entities to layout resources.

4.5. Import/export functionality

14. Interfaces for importing/exporting geometry models of different formats, vendor specific as well
as system neutral formats such as ISO 10303 STEP.
15. Ability to combine imported models with existing layout e.g. by recognizing and interrelating coordinate systems in models of different file formats.
16. Interfaces for importing/exporting models with other properties in different formats.
17. Interfaces for importing/exporting parametric models in different formats.
18. Interface for importing point clouds from laser scanning plus ability to use scanned data for verification.

4.6. Present layout information for human consumption (geometry and properties)
20. Present layout information during design (through CAD interface).
21. Present layout by traversing the model, that is by simulating a “walkthrough”.
22. Make video of various walkthrough with animation of moving resources.

4.7. Analyse layout – ability to:
23. Measure and calculate distances, areas or volumes – during CAD or during the traversing of a model.
24. Quantitative analysis of layout – analyse whether all quantitative constraints on distances are met.
25. Qualitative analysis of layout – analyse whether all qualitative constraints on distances are met.
26. Detect dynamic collisions based on movements and positioning of resources.
27. Calculate center of gravity of a resource model and weight based on material and volume.

4.8. Model management
28. Organize structure of layout model and manage engineering changes.
29. Enable planning how a layout should be realized by showing the sequence of installations of factory resources in relation to the time plan of installations.

4.9. Layout in relation to other manufacturing information and functions – creating the digital factory
30. Show/define flow of material in relation to the layout areas.
31. Show/define manufacturing concept.

5. Conclusion
A well planned factory layout provides the fundament for a profitable production. Designing a factory means designing a system comprised of components of various kinds - such as building, machinery, foundation, media (ventilation, electricity, and plumbing) and material handling equipment – developed by different stakeholders. These stakeholders have different views of the layout; they typically belong to various organizations and often use different software. Further, a factory layout has to be exact for productivity reasons and installed equipment is often difficult to move due to the high degree of interdependency between various parts.

Thus, layout design is a highly collaborative activity which requires combining different perspectives, considering stringent geometrical and functional constraints and interdependencies.

In this paper, functionalities of software tools which can support the factory layout design process to shorten design time and identify errors in early stages of design are investigated. Some of the main functionalities, apart from drawing a layout, are the abilities to combine layouts from different sources through interoperable models; facilitating resource modeling through libraries of parametric 3D digital models; and managing changes in the structure of interdependent models from various vendors.

References