Comparison of Flexsim and Delmia simulation software to reduce current manufacturing layout planning problem

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Abstract—.

Today, volume uncertainty and customer requirements are more dynamic due to reduced product lifecycle in manufacturing. Managing uncertain market demand and rapid introduction of new product development are the key focus areas for manufacturers. This adaptability can be achieved only if a manufacturing industry adopts a flexible manufacturing system. The layout planning is an important factor that influences adopting flexible manufacturing system. Since achieving competitive advantage in the uncertain market demand is the focus of many manufacturers, layout modifications should not be a constraint. Thus, the scope of the project is to understand the current problems in layout modification and how the manufacturers can eliminate them using 3D simulation software. An automobile manufacturing company 'X' is used as a source for this entire research. This exploratory research uses both deductive and inductive approaches. Deductive approach is used to understand the problem and selection of suitable simulation software that supports layout planning. Inductive approach is used to evaluate the significance of the identified problems through a survey from targeted company. Inductive approach is also used to compare and examine the application of the selected simulation software packages viz., Flexsim and 3DS by Dassault Systems to overcome the layout planning problems using real case studies from the targeted industry. The integration of dynamic analysis results with layout planning process to improve planning accuracy and reduce layout modification, have been illustrated in this research. An equation to estimate area based on simulation output and derive layout design input have also been demonstrated through this exploratory research. Based on the results and findings, a framework has been proposed to use 3D simulation for layout planning in the manufacturing industry. This framework benefits manufacturers to overcome maximum identified layout planning problems that exist in today's manufacturing.

Index Terms— manufacturing layout planning problems, software selection for layout planning, comparison of simulation software, Flexsim, Dassault Systems, framework for layout planning using simulation, layout planning process, layout planning tools

1. Introduction

The two big challenges in current automobile manufacturing industries are, the rapid introduction of new product development (NPD) projects based on customer requirement and managing uncertain market demand. In the last 10 years, manufacturing product lifecycle (PLC) reduced by 15 % and the product varieties increased by 40 % (Sabadka, 2013). Increase in product varieties and drop in PLC adds complexity to manufacturing process design, as, product customisation requires corresponding modifications in production process and the layout (Mourtzis,2014).

A layout contains information about material flow and product flow that support manufacturers to decide on an appropriate layout design with minimum modifications. It influences material handling design in manufacturing that contributes to 65 % of total manufacturing cost, in which, 30-40% of cost can be reduced through optimum layout design. (Más & García-Sabater, 2016). In traditional two-dimensional (2D) layout planning, decisions are not objective, but subjective, based on expert's knowledge. The lack of a holistic approach to layout planning provides minimum information in the 2D layout. Layout designers require profound knowledge in mathematics to validate and optimise the designed layout using algorithms and equations (Chae & Regan, 2016b). The major drawbacks of using an algorithm or mathematical equation for layout analysis are, assuming production flows to be constant and using static analysis techniques (Azadeh & Moradi, 2014). Tabu search, genetic algorithms and simulated annealing (SA) are the most common optimisation approaches to solve layout location problems, out of which, SA is the most preferred tool to solve layout problems (Arostegui Jr *et al.*, 2006).

The use of these tools to optimise the entire plant layout with multiple objectives is time consuming and challenging, due to fact that layout design engineers possess minimum mathematical knowledge to solve complex problems (Azadeh & Moradi, 2014). Thus, the results become inaccurate while optimising a factory level layout design.

Simulation enables integration of both time-dependent descriptions of geometry and complex data. Spatial representation and simulation of manufacturing layout in the virtual world help to analyse the dynamic behaviour of the designed layout and its performance, thereby supporting manufacturers to migrate from subjective decisions to fact-based decisions (Choi *et al.*, 2015). In the 1990's, 3D simulation was used only for military training and to train pilots using virtual flight simulator (Page & Smith, 1998). Once the integrated simulation recovered problems of subjective decision making, difficulty and time spent in its execution in manufacturing, its application was widely used in product design than process design.

A manufacturing process simulation requires definition of material flow, product flow and information flow from equipment level to enterprise level. The two major reasons for not using simulation for process design are, the lack of integration between the different levels of manufacturing systems and the increased difficulty in designing a manufacturing process in 3D simulation. More research is needed to be established on data integration between design tools and simulation software for layout planning in manufacturing to overcome the current method of communication within the production system (Oyekan *et al.*, 2015).

2. Stages in layout design process and its challenges

Layout design is carried out in the early stages of manufacturing in NPD, being a dynamic and iterative process due to changing constraints of the production environment. Traditionally, layouts were used as a tool for positioning facilities in the shop floor and to analyse the material flow. But today, they must provide detailed information by correlating behaviour of different levels in the manufacturing system (Madhusudanan Pillai *et al.*, 2011).

Improper re-layout planning creates bottlenecks, increases number of material handling stages, increases resource idle time, reduces efficiency and productivity in manufacturing (Naik & Kallurkar, 2016). Hence, an effective layout design process is vital for manufacturing industry to sustain a competitive position in the market. A good layout is usually backed up with results analysed with broad range of data. The stages of systematic layout planning (SLP) varies from industry to industry, but the purpose and content remain the same (Su & Hwang, 2017). Figure-1 depicts the four stages of layout planning, divided into two sub-categories.

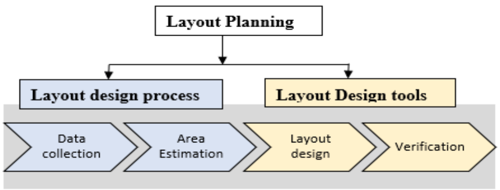

Figure 1: Layout planning stages

In an automobile manufacturing industry, each product has more than 1000 lines of bill of materials (BOM) which require 'xx' time to enter the data manually, as a result, chances of error becomes high. Lack of centralised data management tool for layout planning consumes more time to collect and consolidate data. Many organisations still use spreadsheets for data management, considering its ease of use. Engineering change (EC) management with stand-alone tools leads to use of inaccurate and inconsistent data for layout planning, as change in one process will not reflect in another process. Area estimation output sheet depicts the total required area achieved after comparing estimated area and the available area for new product and volume ramp-up project. Area creation in manufacturing plants is achieved through building expansions, mezzanine creation and process re-engineering etc. All the three changes require significant layout modification and a huge cost for implementation.

Chae & Regan (2016a) claims that the accuracy of an estimated area in manufacturing plant layout planning is only 80%. An error in input data has a major impact on layout design (Naik & Kallurkar, 2016). The error in input data is mainly due to the use of stand-alone tools and lack of dynamic analysis. Also, the sequential approach for layout planning requires modification in the subsequent process that is associated with the robotic cell. An error in area estimation increases the number of iterations in layout design, resulting in increased layout modification implementation lead time (Slack, 2017).

3. Challenges in layout planning

If a company fails to design an optimum layout, it reduces both productivity and business performance of the industry. An ineffective layout design also impacts on material handling cost which result in increased manufacturing cost. Layout designing is being iterative, as it requires modification during every new product introduction (NPI) and volume ramp-up. Lack of flexibility in terms of both volume and product variety leads to customer dissatisfaction by delivering late, and also affects the brand reputation which is very difficult to rebuild (Ackermann *et al.*, 2013). To improve flexibility and time spent in layout planning, computer simulation is introduced in manufacturing. In simulation software, the inbuilt optimization algorithms analyse complex data set in seconds without the need of adequate mathematical knowledge, which is currently lagging for the layout designers (Azadeh & Moradi, 2014). In addition, simulation analysis also provides immediate feedback about layout design with statistical performance output. This benefits manufacturers to analyse the layout design before implementation, which reduces both cost and time.

Many manufacturing industries focus on the fourth industrial revolution which is about combining manufacturing system with information technology to achieve integration and intelligence between systems (Trstenjaka & Cosica 2017). Despite, software developers claim that their products support in achieving integration and intelligent manufacturing systems, it is not reliable information. Simulation increases complexity in manufacturing due to lack of integration between design and simulation software(Oyekan *et al.*, (2015)). Since, the perception on simulation is contradictory, it is further investigated with literature and case studies.

4. Layout design and verification tools

The traditional design of manufacturing plant layout design with the use of rulers and drafters disappeared after mid-sixties due to the evolution of computers. One of the major drawbacks of computer programs is, considering that all the departments, workstations, equipment has regular rectangular shapes, which is not applicable to manufacturing (Bock & Hoberg, 2007).

Liggett (2000) argues that AutoCAD 2D is the widely used graphics user interface software for layout planning in manufacturing industries. Although 2D layout design is considered as an old technology for layout design, it still exists in many manufacturing industries because of its ease of use feature and requires minimum time for layout design. But, the design in 2D is not easily understandable due to lack of detailed information in the layout (Sharma *et al.*, 2013).

Factory-level layout design in 2D requires consolidation of layouts from a different department, as the objective of layout planning and type of layout design varies between different departments in the organisation. Consolidation of different layout requires more time and increases complexity due to use of different positional reference for layout design based on the objective. The chance for data loss during data translation is also high that leads to an error in layout planning and increases the layout modifications (Neghabi *et al.*, 2014).

The lack of attention to the third dimension in layout planning leads to risk during layout implementation. Despite, the evolution of Auto CAD 3D support to visualise the layout in all the three dimensions, it helps to reduce only positional risk, not a functional risk. This is due to lack of kinematic analysis application in the layout design software. Material flow and the position of equipment are validated and optimised using 'from -to' chart, string diagram and activity relation diagram.

To analyse the entire factory flow using these traditional tools is more complicated and requires more skill. Despite, there are several statistical analysis tools to overcome these problems, lack of knowledge and complexity are the major challenges for the layout design engineers (Dangelmaier *et al.*, 2005). Hence, considering the importance of the layout problem and the challenges involved in layout planning tools, further research is focussed only on identifying the problem associated with layout planning tool and process.

5. Problem with layout planning process and tools

5.1 Sequential approach of layout planning

According to Tong *et al.*, (2003), the four major EC that require layout modification in manufacturing industries are: change in process parameters, change in production volume, introduction of new product variant and productivity improvements. In that context, all the four EC require rigorous coordination between departments to collect input data and design layout based on the changes, which increases complexity of data collection for layout design engineer during an engineering change.

In traditional layout planning process, a small modification in the process or any input data, requires sequential modifications in the overall layout. Since the number of iterations are increased in layout planning, the implementation of layout modification for an EC consumes more time. Traceability of layout modification is also difficult to maintain with the use of stand-alone data management tools (Büscher *et al.*, 2014). This leads to erroneous layout planning, which increases the number of layout modifications in manufacturing.

5.2 Lack of importance to dynamic behaviour of manufacturing systems

Today, process automation is more common in many manufacturing industries to improve productivity and reduce labour cost. The human tasks are replaced by robots, or a robot replaces human in the manufacturing process. For instance, painting booths in many manufacturing industries are replaced by robots considering human safety (Engelberger, 2012). However, introduction of process automation increases complexity to layout design engineer, as the existing process relies more on static system behaviour, not on the dynamic behaviour.

The designed layout is verified only during the actual implementation of the system. Layout design without considering the dynamic behaviour of the system creates both operational and financial risk (Krishnan *et al.*, 2009). Therefore, lack of importance to the dynamic behaviour of a manufacturing system in layout planning results in increased number of layout modifications.

5.4 Decisions based on expert's knowledge and minimum set of input data

The limitations in current layout planning process are, layout design cannot incorporate the real production process parameters viz., process speed, takt time, mean time between failure (MTBF), Mean time to repair (MTTR) of an equipment etc. Since, the layout design process contains only limited information for layout design, the accuracy of the estimated area will not match the actual production requirements (Drira et al., 2007).

Despite, layout planning is made by the experts from different domains in an organisation, lack of detailing to the process parameters and qualitative evaluation criteria leads to layout design failure (Tompkins *et al.*, 2010). Dhouib *et al.*, (2009) also acknowledges that the layout planning by the experts without considering the production uncertainties in the process, affects the system throughput. The author demonstrated this with a multi-model machining line with un-buffered stations. The non-holistic approach in layout planning process and lack of importance to the production parameters incur a huge cost for layout modification.

5.3 Gaps in current layout planning tools to create 3D layout design

Despite, 2D layout provide a complete visualisation of the floor plan in the factory with clear annotations, lack of detailing to the third dimension creates a major impact during implementation. The third dimension in the layout planning is more critical and helps the organisation to mitigate associated risk in layout design before implementation (Kjellberg *et al.*, 2009). Use of 3D design instead of 2D for process design improves design quality, aids to mitigate risk proactively, reduce design validation and verification lead time (Sharma *et al.*, 2013). 3D model creation consumes more time than 2D design due to lack of parametric design feature, as it increases the lead time for spatial modelling (Sebastian, 2011). Evolution of parametric 3D design helps to create a 3D model stored in catalogue and supports reusing the same model in layout design only by changing the parameters.

Despite the benefits of 3D layout, transferring information from the Top floor (planning department) to the shop floor (Production department) is difficult in 3D. In that context, the 2D layout is more convenient to transfer data through printouts to all stakeholders and production supervisors.

But, plant layout design in 3D requires an engineer to carry the computer to all places which are not possible in production shop floor environment (Sharma *et al.*, 2013). Hence, conversion of 2D to 3D layout is not the only problem that exists in manufacturing, conversion 3D to 2D layout is also a manufacturing industrial need which doesn't exist in available commercial layout planning software systems.

5.5 Data compatibility issues

Many authors claim that migrating from 2D layout to 3D layout design adds more complexity to the layout design engineers (Gregor & Medvecky, 2010). The data format used for layout design varies from industry to industry. For instance, layout design using different software systems create output in different data format. Shariatzadeh *et al.*, (2012b) author claims that for 2D design .dwg, .dxf and for 3D model,.stp,. exp are the commonly used formats in manufacturing industries. The currently available 3D modelling software will not support all the data format due to technical complexity, and few as a business policy by the software developers to promote software sales. To import unsupportive file format in the designing software, the design data format requires conversion which leads to incomplete data transfer. Because, the chance for data loss during data format conversion is high and anomalies exist during import of different 3D modelling formats.

Initial graphics exchange specification (IGES) is the standard CAD exchange format which supports only surface modelling, which is majorly used for design analysis viz., finite element analysis (FEA) not majorly for the process (Association, 1996). The major drawback of iges is that, it will not support solid modelling which is widely being used by manufacturers. Thus, the international standard for exchange of product (STEP) is widely being used in manufacturing for product model data exchange which supports surface and solid models (Bhandarkar *et al.*, 2000). The international standard for data exchange cascaded IGES in manufacturing. However, still many manufacturing industries adopt IGES as data exchange standard. Thus, many modelling software packages support both IGES and STEP standard file formats.

Most of the manufacturing industries use IGES files for manufacturing product creation, which will not support product structure information and product assembly information. The data conversion from IGES to STEP leads to model anomalies. Both the formats do not support kinematic information and leads to provide incomplete data during data transfer.

Data loss during data transfer is not visible many times during spatial representation. Different departments use different types of layout with varied purposes and different reference points in the layout design as shown in Table 1 which also result in data compatible issues. This requires consolidation or sometimes leads to modifying the reference point to integrate the layout design where the chances for data loss is high.

Despite, 3D layout planning improves visualisation considering the data compatibility issue in 3D layout design software, many organisations still resist migrating from 2D (Ackermann *et al.*, 2013). Hence, the major expectation of manufacturing industries from the 3D layout design software is supporting both standard data exchange formats and inbuilt data conversion software along with layout planning and reduce number of iterations.

Layout type	Department	Purpose	Reference point
Block layout using standard shapes viz rectangle, square, circles	Personnel	Legislation	Building
Building Layout with proper annotations and different views	Civil	Construction and planning	Origin
Detailed layout with all equipment and resources represented in top view with all annotations	Production	Improvement & Flow analysis	Origin and pillar or wall inside the building
Utility layout with electrical routing and annotations	Central Utility	Electrical and plumbing	Pillar and wall inside the building

Table 1: Layout planning process involving different departments

5.6 Lack of collaborative layout design feature

Collaborative design reduces two-third of layout design lead time and reduces modifications, as consolidating and tailoring different independent layout design consumes 60% of the project time (Chen, 2017). Through a collaborative design approach, the issues with data integration and inter-dependencies between the departments can also be eliminated. For example, both civil and engineering department can co-create the layout design in 2D and 3D concurrently using a collaborative design tool.

Collaborative software planning tool configures knowledge to the computer system and improves design accuracy using data that can identify, trace, reuse and consistent in all the planning levels. With the aid of collaborative software planning tool, the change management becomes simpler and it improves accuracy level in layout planning (Menck *et al.*, 2012). Hence, manufacturing industries look for a tool that supports collaborative design between the department using the same software.

5.7 Lack of Integration between 3D modelling and simulation software

The verification of layout design in different aspects such as space utilization, positional accuracy, functional analysis, ergonomics etc., helps to identify the errors in design before implementation and reduces overall layout planning lead time. But, existing layout planning tools support only static analysis through which only the space utilization can be verified. Although there are several tools that support layout design in 3D which includes both space utilization and positional analysis, the lack of feature in 3D design software to analyse the dynamic behaviour of the system is a major drawback (Sharma *et al.*, 2013).

Dynamic analysis can be performed using both real and virtual model. Kaihara *et al.*, (2017) author claims that the simulation software supports dynamic analysis of layout design in 3D. But the integration of both 3D modelling and simulation using the same software is yet to be established. Lack of integration requires re-uploading of models in two different stand-alone software systems, which consumes more time and chances of data loss during integration are also high.

The identified problems through this analysis are used as evaluation criteria for selection of suitable simulation software. However, the significance of the identified problems require validation with the primary data to increase the credibility of the findings. A summary of problems in layout planning process and tools is depicted in Table 2 below.

The problem in the layout design process	The problem in layout design tools
Sequential approach for the layout planning increase number of iterations	Gaps in current layout planning tools to create a 3D layout design
Lack of importance to dynamic behaviour of manufacturing systems	Data compatible issue increase design complexity for layout design engineer
Layout modification decisions are based on expert's knowledge with a minimum set of input data leads to error.	Lack of integration between 3D modelling and simulation software impact layout design verification.
Lack of risk assessment before implementation	Lack of collaborative layout design feature

Table 2: Summary of problems in layout planning process and tools

6. Simulation in manufacturing

6.1 An overview

Simulation is also used in all fields of engineering and service industries for analysis. Accordingly, in my opinion, simulation in manufacturing is defined as a method of representation of the real system using models for the characteristics analysis of the system before implementation. Simulation is not new for manufacturing and the stages of evolution of simulation.

The integration of simulation with a manufacturing execution system is the state of art of simulation in manufacturing as shown in figure-2 (Mourtzis *et al.*, 2014). Simulation is the combination of both mathematical modelling and experimental analysis of the system with a virtual model of an actual system (Fishman, 2013).

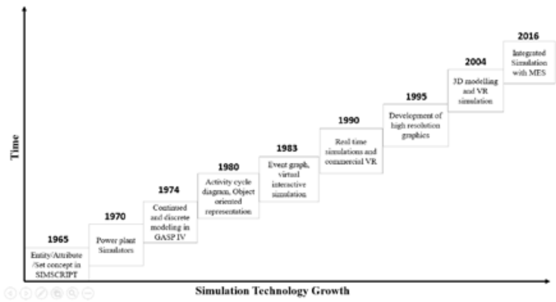

Figure 2: Art of simulation

The main objective to use simulation in manufacturing is to perform dynamic analysis of a system. Two different types of system model's taxonomy exist viz., deterministic and stochastic. Deterministic static model is analysed using mathematical equations, whereas, the deterministic dynamic models are analysed using system dynamics (SD) simulation. The stochastic dynamic model is analysed using continuous and discrete event simulation. Generally, in manufacturing the production system models are stochastic, not deterministic (Tako & Robinson, 2010). Therefore, both continuous and discrete event simulation are more appropriate for manufacturing industries.

Manufacturing industries like automobile focus more on discrete event simulation than continuous simulations. Because, in manufacturing, the processes are discrete and not continuous, only industries like fluid and fabric processes focus on continuous simulation. Certainly, the focus of the project is on layout design in a manufacturing industry like automobiles, the scope is restricted only to discrete event simulation (DES) and its types, not on continuous simulation (Robinson, 2004). Hence, further research is focussed only on the discrete event simulation.

Fishman, (2013) & Robinson (2004) authors also claim that shifting from analysis to business intelligence (BI) is a state of art for DES in manufacturing industries. The business intelligence software comprises of both predictive technology and data analysis capability. Data analysis includes analysis of unstructured data such as production metrics, customer attrition etc., and the predictive technology helps to evaluate different options to make the right business decisions. The BI shift the management focus from getting an information to create an intelligent system to use the information to design an intelligent system. However, it requires integration in different levels of simulation in manufacturing to achieve this BI paradigm through simulation.

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6.2 Virtual factory and different levels of simulation

Today, due to the growth of digitalization in manufacturing, the scope for the virtual model and simulation increased immensely (Boschert & Rosen, 2016). According to Chawla and Banerjee (2001), a virtual environment 'provides a framework for representing a facility layout in 3D, which encapsulates the static and the dynamic behaviour of the manufacturing system'.

As indicated in figure-3, the manufacturing system is classified into two blocks, Manufacturing design system (MDS) and the Manufacturing execution system (MES). The virtual factory layout acts as a manufacturing simulator which integrates both MDS and MES. The main objective of manufacturing system simulation is to evaluate the material flow and the information flow as a system, not as an entity. According to the ISO CIM reference model, the manufacturing system is classified into six different layers. From which the virtual factory is categorised into four viz., equipment level, cell level, factory level and enterprise level (ISO/TR10314-1) (Hibino *et al.*, 2006).

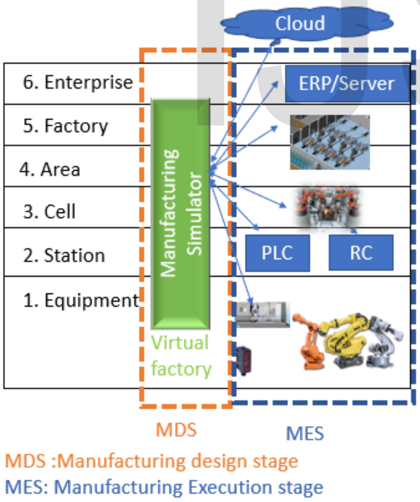


Figure 3: Different stages of the simulation

Firstly, equipment level model support planning and evaluation of a process or an equipment. It includes path analysis, movement analysis, collision detection analysis etc., Since, the main objective of the equipment level modelling and simulation focus on the kinematic analysis of a model. The spatial inference of an equipment with respect to time is analysed in this stage. The level of detail involved in equipment level modelling is comparatively higher than other levels. Secondly, the cell level modelling is the extension of equipment level modelling which integrates one or more equipment. In this cell level, more than spatial analysis or kinematic analysis, the flow of different discrete equipment and processes are being analysed with respect to time.

Finally, the factory level modelling is the integration of both equipment level and cell level modelling. Each level of modelling has a different purpose and provide different set of information to the engineers. Since layout planning is involved in all the three levels of modelling and simulation, the tool that integrates all the three levels of simulation reduces errors in the layout planning. It also helps to achieve the state of art of simulation which is achieving the BI paradigm through integration of all the three levels.

6.3 Challenges and importance of using simulation for layout planning

The traditional two-dimensional layout drawing provides only limited information and requires prior knowledge to understand the drawing. But through the evolution of 3D modelling and simulation, the visualisation is improved, and it provides management with informative data that supports decision-making process. Factory-level layout planning in 3D modelling involves different types of models designed using different software systems and data compatible with standard data exchange format is one of the biggest challenges for the manufacturing industry. Similarly, accurate representation and customisation of 3D model based on user requirement to reduce overall layout design lead-time is still a complicated process and to be simplified (Mourtzis *et al.*, 2014). Thus, ***data compatible with standard data exchange format without error, accurate spatial representation and customisation of the model are the major requirements from manufacturers to eliminate layout modifications.*** However, considering the advantage of improved visualisation and amount of information attained through modelling and simulation, using simulation in manufacturing industry increased drastically in the last three years.

The product varieties and volume fluctuations in manufacturing require layout modifications. The reconfiguration of facilities and machines during each modification in manufacturing plant is more expensive and time-consuming process. Likewise, changes in equipment level modification lead to cell level and factory level modifications of the layout. Due to increased complexity in layout planning, only with the existing 2D layout planning tool and static analysis, efficient layout design cannot be achieved. Despite, dynamic analysis of layout design can be achieved using stochastic discrete event simulation, lack of an integrated tool increases modification. Lack of integration to perform kinematic analysis and system behaviour is a major drawback. It requires transferring the data and function from two independent software systems, which results in the use of an incomplete model that leads to inaccurate layout planning. Hence, ***an integrated tool for both kinematic and layout simulation is one of the important requirements for manufacturing industries.***

The focus of manufacturers on digital manufacturing practices to react fast to the market also create a disruptive situation for the layout engineers. Because, more than 55% of new manufacturing technology implementation to adopt digital manufacturing requires major modification in factory layout. The main reason for focussing on digital manufacturing is to promote collaboration between manufacturing design system (MDS) and manufacturing execution system (MES). The virtual factory design and simulation helps to achieve digital manufacturing by collaborating product, process and resources design simultaneously through the existence of 'digital twin'. Despite, simulation supports collaborative manufacturing through the existence of 'digital twins', lack of integration between modelling and simulation software systems require external software for data translation. The data translation loss and lack of a feature to support both modelling and simulation with integrated product data management (PDM) throughout the product life cycle increases layout modifications (D'Antonio *et al.*, 2017). Büscher *et al.*, (2016) also acknowledges the existence of the problem and suggests that development of simulation software with integrated product lifecycle management (PLM) tool support manufacturers overcome the problem of using inconsistent data in modelling and simulation. Hence, ***an integrated PLM simulation tool integrates both modelling and simulation without requiring any external software for data translation is the important need for the manufacturer to eliminate errors in layout planning.***

6.4 Evaluation of different layout design and simulation tools

The focus of the project is to select the suitable simulation tool that supports manufacturing layout planning. The challenges listed in table-4 are used as an evaluation criterion for the simulation software selection. There is more simulation software available in the market, however, evaluation of all the software is not a feasible solution. Since the objective is on manufacturing layout design, the software that supports both manufacturing and layout simulation is analysed based on the evidence from literature and website information which helps to narrow down the analysis to five software as depicted in table-3.

DES Softwares	Manufacturing	Layout Simulation	General	Others
Any logic	✓	✓	✓	
Arena	✓	✓		
Dassault systems (Delmia)	✓	✓	✓	
Flexsim	✓	✓	✓	
Plant Simulation	✓	✓		

Table 3: Comparison of DES software systems

In addition, the software is also evaluated based on the general software evaluation criteria viz., hardware, software, ease of use etc., To simplify the evaluation process, the evaluation criteria are weighed and ranked. The weight is decided based on a research article (Mourtzis *et al.*, 2014; Shariatzadeh *et al.*, 2012a) and the previous experience of the researcher in layout planning in the manufacturing industry. The weight for integrated PLM support and the software that supports both kinematic and DES are weighed higher considering the impact it creates in layout modifications. As shown in below table, only 3DS by Dassault Systemes software and the plant simulation by Siemens met most of the requirements that support manufacturing layout planning. Yuan (2012) claims that the flexsim is one of the novel software to build a manufacturing system in 3D. However, analysing all the three software systems with the identified problem consume more time. Also, to analyse all the features and availability of license for the complete version of the software is also critical. Since student license for 3DS and the flexsim are already available with the university, further research is analysed only with flexsim and 3DS software.

Source	Criteria groups	Evaluation Criteria	Weightage	Any logic	Arena	Plant simu	Flexsim	Dassault
Problems in layout planning identified through literature and survey	Layout design process requirements	Evident based decision making	5	5	5	5	5	5
		Concurrent Engineering	5	0	0	5	0	5
		Integrated product data management	5	0	0	5	0	5
		Risk assesment	5	3	3	5	4	5
	Layout design tool related Requirements	Design in 3D and Customization features	5	2	2	5	5	5
		Data compatibility	5	2	3	4	3	5
		Colloborative design	5	0	0	3	0	4
		Integrated 3D design and analysis	5	2	2	4	3	4
		3D to 2D conversion	5	0	0	3	0	5
Requirements of manufacturers from the simulation software (Literature)	Hardware and Software	Design without Coding knowledge	3	2	2	2	3	2
		Software Compatibility	3	3	2	3	3	3
		User support	4	4	2	4	4	4
	General features	Experience required	4	3	4	3	3	3
		Ease of use	5	3	2	3	5	3
		On-line Help	5	4	2	3	4	5
	Modelling assistance	Library and templates	5	3	2	4	4	4
		Visual Aspect	5	3	3	4	3	5
	Simulation capabilities	Statistical data	5	4	3	4	5	4
		Experimentation facilities	5	3	3	4	5	5
		Kinematic and DES	10	0	0	8	5	9
	Input/output	Input/output capabilities	5	4	3	5	4	5
		Analysis capabilities	5	5	4	4	4	4
	PLM	PLM Support	10	1	1	5	1	5
	Data storage	Cloud support	5	1	1	4	1	4
		Total	700	273	236	463	371	548
		Ranking		5	6	2	3	**1**

Table 4: Evaluation of simulation software

6.5 Flexsim

Flexsim, a discrete event simulation software supports manufacturing industries to analyse the manufacturing layout planning in 3D. The user interface of flexsim is also simple and easy to understand as shown in figure-4. The existing library, toolbox and the quick properties window help designers to create a novel design in 3D with reduced design lead time. This is the first software to introduce drag and drop option to create novel 3D model using existing library and tool boxes. The logic of the model can be built using 2D flow charts of both the processes and directly use 3D model simply by connecting the I/O port. Experimenter and optimization tool integrated with flexsim software enables the designer to perform dynamic analysis without the need of mathematical knowledge. Despite, the user interface is not so attractive with improved graphics features the software support many manufacturers to improve the manufacturing system performance through dynamic analysis.

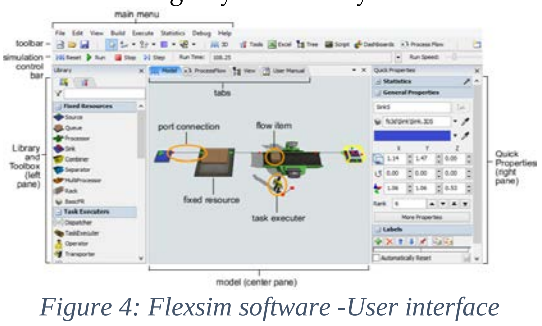


Figure 4: Flexsim software -User interface

Flexsim is also capable of suggesting an optimised solution for the defined conditions of a manufacturing system. This supports rapid dynamic analysis of different manufacturing scenarios before implementation. Flexsim simulation tool is also used to create a value stream mapping and analyse the process using inbuilt statistical analysis tools. Flexsim helps to represent manufacturing system in 3D more rapidly and inbuilt dynamic analysis as shown in appendix 4, thereby supporting manufacturers for fact-based decisions. A rail system bearing manufacturing organisation adopts flexsim simulation tool for process optimization to identify and eliminate all non-value adding activities. Since, the main objective of the system is to optimise the process and reduce inventory which also influences the layout and space utilization factor as shown in figure-5 (Anon, 2017). Hence, through flexsim process simulation, the layout design can be optimised which helps manufacturing industries for evidence-based decisions.

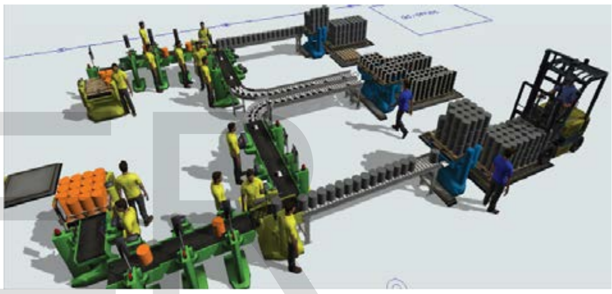


Figure 5: Process optimisation and inventory analysis using Flexsim

On the other hand, limitations in the creation of a customised 3D design to represent a product or resource in flexsim are one of the major drawbacks. Since the bearing can be represented using basic shape viz., sphere from an existing model library in Flexsim, the model creation is simpler. But, to represent motorcycles, the car in the Flexsim process flow requires customisation. Customisation involves format conversion, import and scaling of defined product into the software which consumes more time and increases difficulty. It is not highlighted in any existing academic research.

Limitation in terms of data compatibility, kinematic behaviour analysis, integration of virtual model with real model and stand-alone nature are the major drawbacks of Flexsim software to consider for layout design process (Anon, 2017). Limitation in terms of data compatibility, kinematic behaviour analysis, integration of virtual model with real model and stand-alone nature are the major drawbacks of Flexsim software to consider for layout design process.

6.6 3D Experience by Dassault systems

3D experience (3DS) by Dassault Systemes enables to design a 3D CAD, create engineering model, simulate, manage data using a common platform. 3DS converts the traditional view of creating a stand-alone simulation software into an end-to-end integrated single software tool that supports manufacturers to manage from the design stage to end of life cycle stage. Dassault system initially focussed on a design by creating a Computer-aided design (CAD) and computer aided manufacturing (CAM) software's. The CATIA software developed by Dassault in 1976 for creating the CAD model still exists in many manufacturing industries. Then, by acquiring software for design and product data management viz., solid works, IBM (Enovia) etc., a collaborative platform for project management is created using a single software.

Dassault systems launched Delmia with an objective to support process engineer along with product design engineer using the collaborative platform. Later, the software range extends from CAD to computer-aided systems 'CAx'. Delmia's Queueing event simulation tool (QUEST), a flexible object-based environment for manufacturing system modelling and discrete event simulation. QUEST differs from other DES by integrating CAD model for simulation rather than using the models created using virtual reality model language (VRML) and another graphics software like google sketch up (.skp). The user interface of the QUEST 2000 is as shown in figure-6, which is almost similar to the flexsim current graphic user interface. This indicates that, the technology advancement of Delmia is higher than flexsim in terms of manufacturing process simulation. QUEST supports layout modelling and simulation in both 2D and 3D. Despite, QUEST supports layout simulation, the stand-alone feature is one of the major drawbacks that restricts further development (Salleh et al., 2012). However, understanding the drawback, the magnificence improvement by Dassault system to overcome the drawbacks in the recent years is incredible.

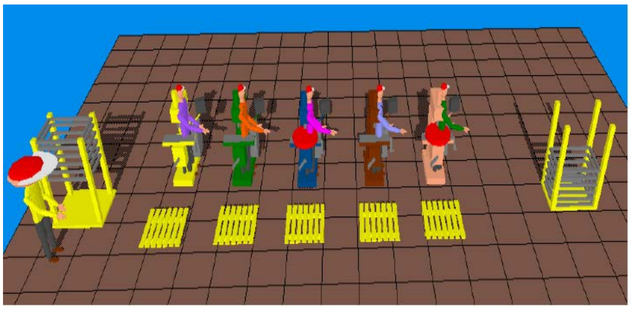


Figure 6: Manufacturing Process analysis using QUEST

The acquisition of different companies by Dassault systemes help to create an integrated and collaborative platform to manage from design to end of life cycle processes. The Dassault Systems comprise of more than hundreds of companies. The 3DS software by Dassault Systems V2018x contains 154 different applications majorly classified into four categories viz., 3D modelling, Virtual and Real-time Simulation, information management and collaborative applications. The number of applications under each category is as depicted in figure-7. Kenneth David, a senior application engineer of Dassault Systemes claims that different application in 3DS is the world's best collaborative tool and provides an integrated solution for any type of industries.

Figure 7: Illustration of Dassault system product and number of applications (Anon, 2017)

According to Franzosa (2017), 3DS is considered as a market leader in manufacturing execution system (MES). MES supports integrated and intelligent manufacturing, which is a major focus of many manufacturing industries to achieve the fourth industrial revolution. Dassault system through MES promotes the cyber-physical system, where the physical and digital models intertwined as 'Digital Twins'. Digital twins are established through integrating product, process and Resources represented as 'PPR context' with the real world. Since the objective of the analysis is to identify a tool for layout design and verification, the application in 3DS that contributes only for layout design is identified, the unique application in 3DS support that layout planning is explained in detail.

6.6.1 Product design

The integration of Solidworks and Computer-aided three-dimensional interactive application (CATIA) in 3DS helps manufacturers to create any digital model in a virtual environment. Because, Solidworks support computer-aided design (CAD) and computer aided manufacturing (CAM), whereas CATIA supports CAD, CAM, computer-aided engineering (CAE) in the integrated platform. Both the software systems are widely used for modelling in many manufacturing industries and the integration of both the software systems is one of the unique features of 3DS.

General product design can be created using different CATIA applications viz., Natural shape, product design, assembly design etc., In addition, there are certain dedicated CATIA applications that support layout planning viz., 2D layout for 3D design and 2D layout insight application. The purpose of incorporating the 2D layout design application is to eliminate the dependencies on traditional 2D CAD software for layout planning which eliminates data compatible issue and support integrated planning.

6.6.2 Process and Resource Design

Digital enterprise lean manufacturing interactive application (DELMIA) in 3DS platform helps to design manufacturing process, operations and define resources. DELMIA supports manufacturers to design and test manufacturing process in a simulated production environment. Despite DELMIA QUEST supports design and analysis of manufacturing process, stand-alone and lack of integration with design application viz., CATIA is a major drawback. But in 3DS, due to integration of product design application and process design applications ***it enables to analyse both kinematic and discrete event simulation using the same application***. This is one of the major requirements by the manufacturers to overcome layout planning problems.

In addition, the dedicated application of DELMIA viz., process planning, process simulation, plant layout design, equipment design, equipment allocation, factory flow simulation support manufacturing layout planning. Despite, the visual representation of QUEST is not the actual representation of the physical model, the newly integrated 3DS DELMIA visual representation depicts the actual model in a virtual environment. Similarly, the spatial representation of a human in 3DS is better than quest. Despite the importance of human spatial representation is less in layout planning, the dedicated applications viz., ergonomics, ergonomics at work contribute to layout planning. This improved spatial representation is mainly due to the growth of technology in computer hardware viz., graphics support and advanced processor.

6.6.3 Collaborative Data management and information intelligence

Today, manufacturing organisations rely more on automation processes which require 'Digital continuity' to avoid errors and reduce design lead time. Digital continuity refers to data consistency, understanding the change management and workflows from design to after-sales service levels. Digital continuity can be achieved only through integrated product data management and project lifecycle management (PLM). Digital continuity is critical for automobile manufacturing to manage the continuously changing industry standards and customer demand.

Enovia, a PLM software integrated with 3DS support stakeholders to position, assemble and configure product in smart devices with the aid of web interface. This unique feature of 3DS support collaborative business intelligence. The inbuilt data conversion software support manufacturers to reduce dependencies on external data transition software and improve data compatible feature. This 3DS ensures integrated and collaborated platform to design product, process and resources in common 3DS platform. The collaborative platform also supports to share and get immediate feedback for layout design from the users which supports concurrent engineering and helps management to reduce financial and operational risk.

Through integrated product data management, the data in all the different stages of manufacturing is stored in the common platform 3DS. This ensures consistent and coherent data in the entire manufacturing system design which eliminates layout modifications due to use of inconsistent data. Also, the recent release of 3DS in 2016 support cloud-based data management system which ensures data retrieval from the system irrespective of locations. Finally, the information intelligence by EXALEAD in 3DS helps to enrich, align and gather big data. This support to convert multisource data into meaningful data that support manufacturers to improve business performance and gain a competitive advantage (Anon, 2018).

Despite, the 3DS software by Dassault Systemes seems to be the suitable solution for targeted automobile manufacturing industries to overcome identified layout planning problems. The dedicated and integrated applications from CATIA and DELMIA that supports layout planning is as indicated in table-5. The matrix indicates that there are 15 out of 144 applications that contribute to layout design and verification of different factors.

Dassault System													
Product	Domain	Application name	Sketch	Creating 3D Part	Creating 3D Assembly	Design of Layout	Design of Equipment	Design of Equipment simulation	Creating Process	Allocating Resources	Process Flow simulation	Material handling	Factory flow simulation
CATIA	3D Modelling core	Natural Shape		▪									
		Sketcher		▪									
		Part Design		▪									
		Human Design	▪										
	Styling	Natural Sketch	▪										
		Sketch Tracer	▪										
	Mechanical systems	Assembly Design			▪								
		2D Layout Insight				▪							
		2D Layout for 3D Design				▪							
DELMIA	Manufacturing Planning	Equipment Allocation					▪			▪			
		Process Planning							▪				
	Process Flow and Plant	Plant Layout Design										▪	▪
		Process Flow Simulation									▪		
		Equipment Design					▪			▪			
		Equipment Simulation						▪					

Table 5: Applications used for layout planning in 3D Experience software

7. Research Methodology

The scope of this research is achieved using an exploratory approach. This exploratory research follows a mixed approach which involves both inductive and deductive research methods. Deductive method is used to identify the problems in layout planning and to select an appropriate simulation software that supports manufacturing layout planning with an aid of literature. Inductive method is used to validate the significance of the identified problem and the software applications through survey and case studies. This research involves both qualitative and quantitative data for analysis. Qualitative data is collected from the available literature and through a survey from the targeted industry. Quantitative data is collected from the targeted industry to evaluate the significance of the problem and to evaluate the simulation software application through case studies.

The automobile manufacturing ***company 'x'*** is used in the entire research process. Company 'x' is a multinational two-wheeler manufacturing industry with revenue of more than 200 million USD (approx.). The company has four different manufacturing locations and manufacture 10000 vehicles/day. The company has more than 800 tier I supplier and have more than 80 group of companies. Among all the companies, this company alone contributes for 60 % of the total revenue. The company deals with ***10 to 12 new products in a year***. The company has more than hundreds of product variants and ***average sales volume growth is 25% in a year***.

Data collection includes both primary and secondary data to achieve the desired project objective. Primary data from the company 'x' is used to understand the significance of layout problems identified through literature. In addition, secondary data from targeted industry is also used to verify the credibility of collected primary data and it is used to evaluate the applications of simulation software using case studies.

Secondary data from the targeted industry includes the facilities details, dimension, layout drawings, 3D model and other data as shown in table-6. Secondary data also includes the data collected through the online tutorial and the data from the software 'online community' support team to solve the problems faced in the entire 3D layout planning and simulation process.

S.no	Primary data	Data format	Department
1	Layout	AutoCAD (.dwg)	Production Engineering
2	Area Estimation	Spreadsheet (.xls)	Production Engineering
3	Project lead time	Spreadsheet (.xls)	New Product Development
4	Part drawing	3D Step file (.stp)	Production Engineering
5	Production volume	Spreadsheet (.xls)	Operations
6	Machine parameters	Spreadsheet (.xls)	Production Engineering
7	Resource details	Spreadsheet (.xls)	Industrial Engineering

Table 6: Secondary data collected via online tutorials

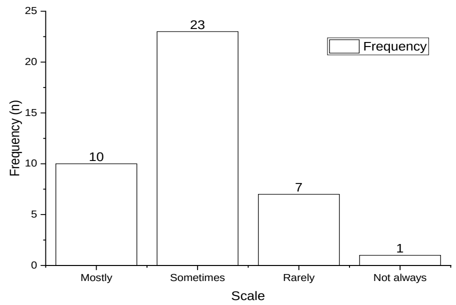
The survey questionnaire is designed with an objective 'To understand the gap that exists in the layout design process and tools' in company 'x'. The questionnaire contains a set of 12 questions and each question is framed with the objective that is interlinked with the overall scope of the project. The survey questionnaire is developed using the 'Qualtrics' software (Snow & Mann, 2013)and the anonymous link is circulated to the targeted audience in the targeted industry. Since the project main objective is on layout planning where many people in the manufacturing industries might not have awareness. A convenience sampling technique is adopted and the anonymous link is sent only to the targeted audience who have prior experience and awareness about layout planning (Iarossi, 2006).The targeted audiences are selected based on the researcher previous experience in the targeted industry .

The purpose of the questions asked in the survey and authors expectation is as listed in table 8. Since the purpose of the survey is only to analyse the significance of identified layout planning problems, the survey results are not used for the research findings and it is used only to validate three different hypotheses. The questions that contribute three hypothesis checking are highlighted with three different colours in the table. The three hypotheses are

H1: Delivering new product / volume ramp-up project on time is a problem for manufactures.

To understand the significance of the problem faced by manufacturers during new product and volume ramp-up projects. The data collected with respect to the frequency at which the new product and volume ramp-up project implemented on time in the targeted industry. Because theory suggests that reacting fast to uncertain market volume and product mix are the key challenges for manufacturers (Ackermann *et al.*, 2013).As shown in figure-8a, the maximum response of the survey indicates that only 'sometimes' that the new product and volume ramp-up project implemented on time. This indicates the presence of a problem in delivering the new product and volume ramp-up project on time in the targeted industry. Therefore, the cause that creates significant project delay in an organisation is analysed with the response of Q5.

The result indicates that a maximum number of times the project delay occurred due to layout problems in the targeted industry as shown in figure-8b. Since, the significance of this finding support project to the maximum extent, the reliability of data is verified by comparing the results with the response of Q4 which is about the frequency of dealing with new product and volume ramp-up project. Only 9% of the people who dealt with new product and volume ramp-up project rarely. This indicates the credibility of data and ensures that layout problem creates significant project delay. Despite, the importance of layout planning varies from industry to industry, in the automobile manufacturing industry the importance of layout planning is always critical to business performance. Hence, with this data, it is clear that layout has a major impact on new product and volume ramp-up projects. In addition, it also helps to understand the importance of other problems that create significant project delay.



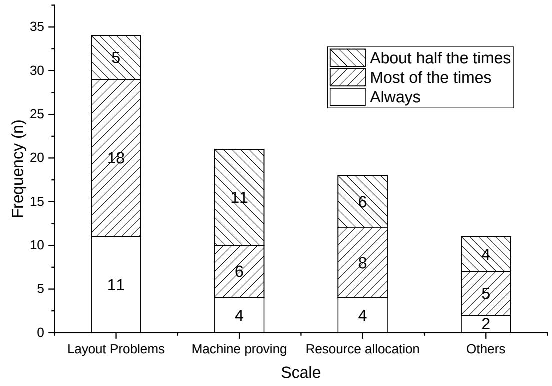


Figure 8: Survey responses for project failure

H2: Traditional layout planning tools are still used in manufacturing for layout planning and it leads to the different type of problem

Liggett (2000) claims that AutoCAD 2D is widely used in manufacturing. Whereas, Sharma *et al.*, (2013)claims that the use of 2D layout planning tools viz., Auto CAD for layout design in manufacturing leads to planning error. He also suggests that lack of detailing to the third dimension in a layout and use of non-updated layout for layout planning are the major causes for planning error. Thus, the survey results of Q7 and Q10 are analysed to understand the significance of the problem that is mentioned in the theory.

As shown in figure-9a, 'AutoCAD 2D' is widely used for layout design in the targeted industry. Because the modal response for the tool that used for layout design is AutoCAD 2D. But, the result is again verified by correlating the frequency of dealing with layout drawing. The result indicates that people dealt with layout drawing more frequently and frequently confirms 'Auto CAD 2D' is used for layout planning (Refer figure-9a). The result also helps to indicate that the AutoCAD 3D is also being used for layout planning.

In addition, to understand the type of problem arise due to the use of 2D layout planning tools, the major problems identified through literature is listed as options and asked to rank based on their experience. The result indicates that use of non-updated layout design and lack of visualisation are the top two identified problems with the existing 2D layout planning tools a shown in figure-9b. Both the problem leads to increase the layout modification in the manufacturing industry. On the other hand, the other two problems ranked as lowest frequencies also have a major impact on layout modifications. Because it creates an error in the layout plan and errors lead to layout modifications. But, for both the problems the

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layout planning process contributes more than tools. Thus, the existence of problem-related to layout planning process in the targeted industry is also known through this finding.

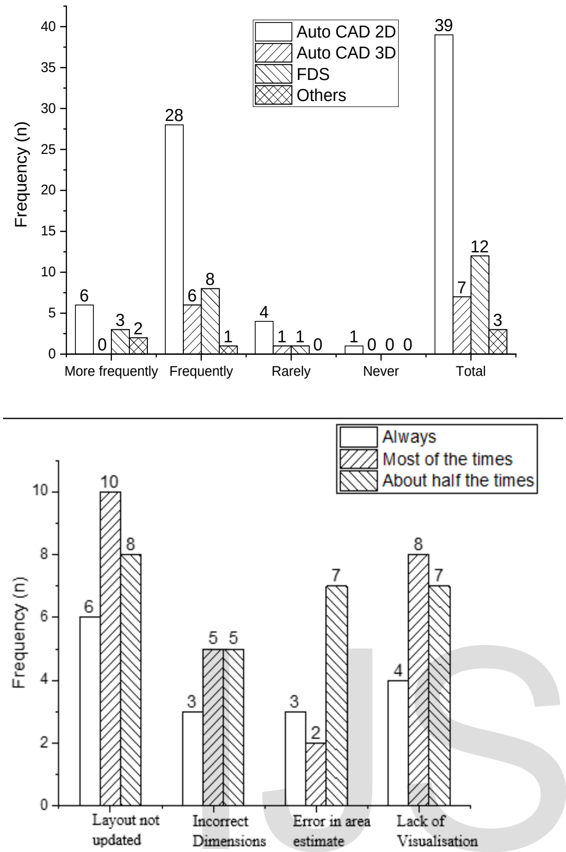


Figure 9: Survey responses for problems in layout planning

H3: Layout design process influence area estimation accuracy and consume more lead time for layout design and implementation

The data collection process using standalone tools lead to inaccurate area estimation and consume more time (Drira et al., 2007). The layout is multidisciplinary which requires an integrated approach to reduce lead time because today 30% of the project time is spent only on data collection and consolidation. Theory suggests that the use of the legacy process for layout planning impact on layout design and implementation lead time during new product and volume ramp-up projects (Alexiev *et al.*, 2005) . Thus, to verify both the problems Q8 and Q9 are framed where the mode of response of Q8 in figure-10a below indicates that area estimation matches only 80% of the actual requirement. However, only with this limited data, the intensity of the problem cannot be identified. Hence, to understand the validity of data the mode of response is correlated with the experience in layout drawings which shows a positive correlation as shown in figure-10b.

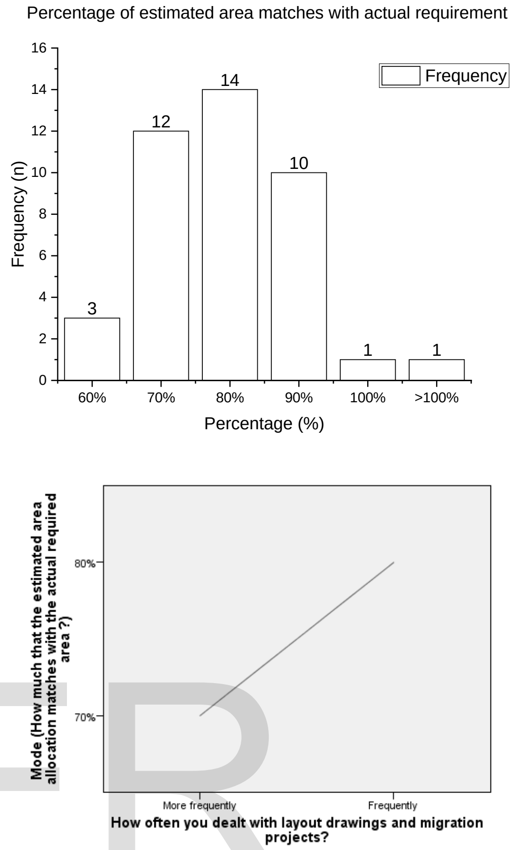


Figure 10: Influence of layout design process

The impact and importance of the area estimation error lead to layout modifications completely varies based on the total area of the project. Even though the analysis shows that the area estimation is only 80% accurate, the impact varies based on total area. For example, the impact of layout modification with 20% error in 100 Sq.m projects and in 1000 sq.m project varies. Hence, to understand the intensive nature of the problem the last six new project data from company 'x' (Table-7) is analysed which shows that error in area estimation varies from 11% to 29%. The data for area estimation is also collected from a different department in the targeted industry. Since the layout planning process involves multiple departments, data inconsistency leads to error. The increased planning error increase the modification in the layout. Therefore, through data triangulation, it is proven that the use of standalone tools and techniques in the layout design process impact area estimation accuracy which leads to increase layout modifications.

S.no	Project	Planning	Design	Implementation	Layout planning
		Estimated Area (Sq.m)	Required Area (Sq.m)	Provided area (Sq.m)	Error (In %)
1	A	9000	9000	11600	29%
2	B	10200	10200	10200	0%
3	C	7500	7500	7500	0%
4	D	7200	7200	6300	-13%
5	E	800	800	800	0%
6	F	4500	4500	4000	-11%

Table 7: Intensity of area estimation mismatch problem

Secondly, the layout design and implementation lead time for new product and volume ramp-up projects are high in manufacturing due to lack of risk assessment before implementation. This is mainly due to the gap that the current layout design process and tools is not competent to analyse the risk before implementation. Since the error identified only in the later stage of the project, the effort to modify and re-design the layout is also complex and challenging (Krishnan *et al.*, 2009). To understand the significance of the problem, Q9 is framed which is about layout planning lead time for new product and volume ramp-up project.

Almost one third and more than half of the people state that the lead-time for volume ramp-up and new product layout design lead time is 3-5 months and more than 6 months (figure-11a). However, the answer leads to the biased decision because the lead time depends on the amount of work involved in the project. Hence, the secondary data about the layout design process lead time for the last ten project which has an equal amount of work is collected and analysed. The average lead time for different stages in layout as shown in figure-11b below. The result obtained from the secondary data almost match with the primary data. Because secondary data result indicates that the design and implementation lead time for new project layout planning is 391 days. Also, this analysis indicates that the layout planning data collection process is the second highest time-consuming process in layout design. Hence, comparing the data from the literature, survey and the actual secondary data of the project in the industry, it is clear that the legacy and non- collaborative layout design process impact on area estimation accuracy which increases the layout modifications. As a result, the layout design and implementation lead time are very high.

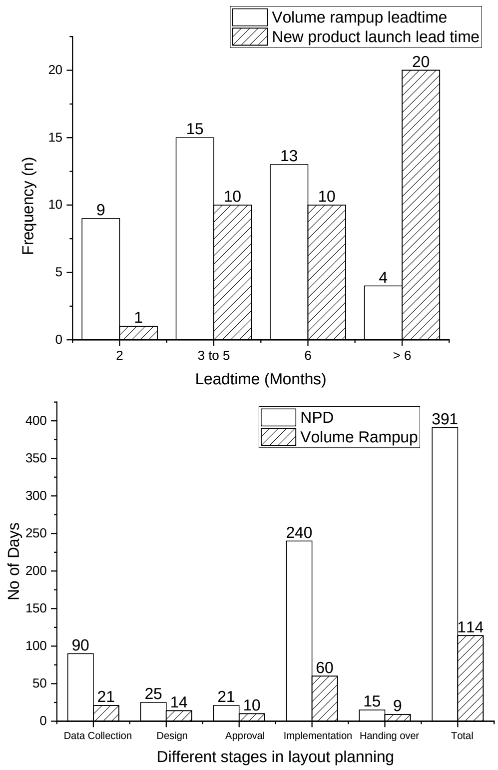


Figure 11: Stages and lead time involved in layout planning

8. Case studies

Three different case studies with different objectives are analysed to compare the competence of selected simulation software viz., 3DS and Flexsim. '3DS version 2018x' and 'Flexsim 2017 update 2' software version with student license is used in the entire case study for comparison. The main objective of three case studies are as follows:

8.1 Case study 1- Compare spatial representation and parametric design features

The spatial shape representation of the model is important for layout design in manufacturing industries to improve visualisation. Because the major problem in manufacturing layout planning is lack of visualisation which leads to misinterpreting the layout design. This is more common in manufacturing industries. For instance, assume that size of bin represented in 2D will not provide valid information that bin is designed for an airplane or fasteners. Because the size of bin varies based on the type of parts to be stored. Since bins are the major sources of queueing in manufacturing, an error in spatial design leads to creating major layout modifications. Thus, the spatial representation is more important for manufacturing layout planning to eliminate modifications. This case study focuses on comparing the spatial representation of bin and steel mezzanine rack.

Firstly, the spatial representation of a plastic bin without a partition is analysed. In 3DS CATIA application 'part design' is used to create a 3D model of the bin incorporating all the design parameters as shown in figure-12a below. The creation of plastic bin in 3DS requires minimal designing skill in 3D design software. In flexsim, the basic shape sphere is used to represent plastic bin with desired length, width and height as shown in figure-12b below. Flexsim does not require any basic designing skill to create a spatial model. This is due to the unique feature of 'drag and drop' option in flexsim. Also, due to this feature, the effort required is also minimal to represent the 3D model of the bin. The effort is quantified here with a number of mouse clicks. Despite, the flexsim representation is not an actual representation of bin, it will not create any impact on layout design. If the spatial representation of bin replicates the actual product dimensions viz., Length (L), Width (W), Height (H). Hence, in this case of representing plastic bin in 3D where the spatial representation is not important, flexsim software is simpler and easier to use than 3DS.

On the other hand, the plastic bins are also designed to handle the special product with partitions. The dimensional and position accuracy is more important in this spatial model of the bin. For instance, assume a kitting bin in manufacturing industry which has to be handled by a robot. The accuracy of the spatial bin model is critical for the positioning of parts using the robot and to create an accurate robot programming. An integrated design application in 3DS viz., CATIA enables the user to create a 3D model of the bin with all dimensional parameters and with desired design accuracy.

Despite, flexsim being the native 3D modelling tool, there are certain limitations to represent customised design in 3D. It includes that the product can be represented only using four basic shapes viz., cube, cylinder, sphere, plane. Lack of integrated design application in the software requires additional design software to design a customised 3D model. In addition, the chance for data loss is high during data transfer from design software to flexsim. All these drawbacks result with an error in layout planning which leads to increase layout modifications. Also, from an organisation perspective, the management must invest in two different software to adopt flexsim software which increases both software maintenance cost and the training cost. Since factory level layout planning involves more customised 3D models, flexsim is not an appropriate solution due to lack of integrated design application.

Hence, through this case study it is clear that the integrated design applications of CATIA in 3DS viz., part design, part assembly etc., the spatial representation is accurate. The increased accuracy in spatial representation reduces the requirement of layout modification.

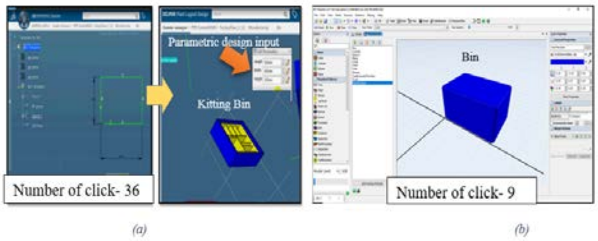


Figure 12: Part design user interface difference between 3DS and Flexsim

The parametric modelling of steel mezzanine using flexsim is not possible. Because it supports parametric modelling only for the basic shapes in the model library. But, in 3DS the integrated design application viz., part design, part assembly by CATIA support manufacturers to design and define the parameters during the design phase using the same software (Figure-13). In addition, it also supports creating a design table through which different type and dimensions can be defined during the design phase. The spatial representation varies based on the selection of type. Despite, the mezzanine parametric design in 3DS requires an additional 20 mouse clicks, the impact is still minimal because the number of clicks required to rebuild the entire mezzanine model in 3D from the beginning requires 64 mouse clicks. The benefit of reducing almost 30% of mouse clicks help manufacturers to reduce the overall the layout planning lead time and enable layout design engineer to modify the model based on requirement only by changing the parameters. Thus, lack of a feature to design a customised model in 3D and lack of a feature to create the customised parametric design is the major drawbacks of using flexsim for layout design. Hence, this case study helps to identify that 3DS spatial representation is accurate and support parametric design that helps manufacturers to reduce layout planning lead time.

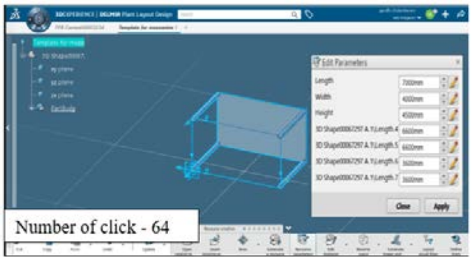


Figure 13: Integration of part design and assembly applications in 3DS

8.2 Case study 2 - Examining data compatible, collaborative planning and ease of use applications

The objective of this project is to eliminate the layout modification, this case study is focused only on examining the competence that supports layout planning. The traditional 2D robotic kitting cell layout (figure-14) company 'x' is used in this case study to analyse different organisation factors considered in simulation software related to layout planning.

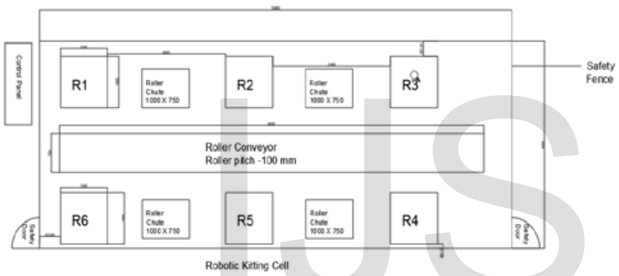


Figure 14: Robot kitting cell 2D layout of company 'X'

a) Examining the capabilities to convert 2D to 3D layout design and vice versa

The traditional 2D layouts are used as a footprint for creating a 3D layout. The design of a layout in 3D without using the 2D layout as footprint leads to positional inaccuracy. Because for accurate positioning of facilities, it requires a point in 2D design as a reference to snap the position of the facility in the third dimension. The facility positioning is critical in layout planning because inaccurate positions in layout planning lead to a design error and it requires modification in the layout at later stages. Also, the inaccuracy in layout position impacts dynamic analysis which leads to taking erroneous decisions. Thus, a feature to support existing 2D layout drawing formats to use as the footprint is the minimum requirement for a layout designing software.

In that context, the feature to import 2D layout drawing is explored in both the software. Both flexsim and 3DS software capable of importing robot kitting cell 2D layout drawing as indicated with an arrow in the figure-15. In addition, the snap feature in both the software helps accurate positioning that improves positional accuracy. The model libraries and catalogues in both the software help to realise robot kitting layout in 3D from 2D with reduced design lead time. The drag and drop option in flexsim require a lesser number of mouse clicks to create a 3D model than 3DS as shown in figure 15.

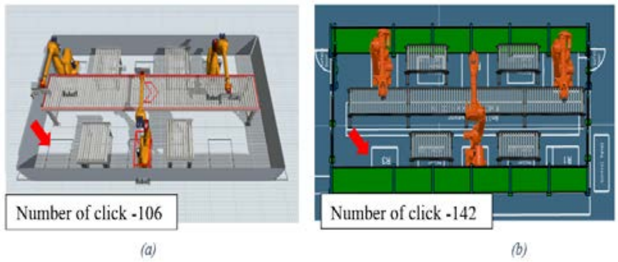
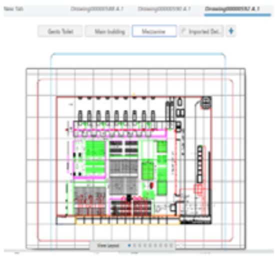


Figure 15: Number of clicks involved in Flexsim and 3DS for robot kitting cell design

On the other hand, importing 2D layout drawing is not straightforward and requires certain prerequisites to be followed to reduce error. Firstly, the metric units of measurement in both 2D and the layout designing software must be the same. Because trying to fit the round into the square will not match. Thus, any mismatch or wrong selection of metric system lead to positional error. Secondly, the file format of 2D drawing must align with the software recommended file format as specified by the software developers. For instance, both flexsim and 3DS support CAD drawings in *.dwg* or *.dxf* format. But, flexsim support layout drawing formats only till 2010 versions whereas 3DS support till the latest version 2018. This is mainly due to the presence of a dedicated design application by CATIA '2D layout for 3D design' which is capable of importing all recent version of 2D layouts. Lack of dedicated application for 2D layout design application in flexsim requires file conversion which increases the design complication by increasing the layout design lead time. Similarly, the chance of data loss during translation is also high.

A manufacturing factory level layout planning in 2D contains multiple sheets in the same file. The practice of creating multiple sheets in the same drawing file is to store all project related information in the same file that supports layout design engineers for accurate design and to eliminate alterations. The different sheets of layout design emphasise different purpose and designed separately to reveal different information. For example, in the robotic kitting cell layout it has four different sheets viz., Kitting cell layout (Mainsheet), mezzanine, main building, toilet etc., The main building and toilet sheets in layout contain civil drawings with dimension which has to be incorporated in factory-level layout planning and lack of importance to the civil dimension requires massive layout alterations. Thus, software capabilities to import multiple sheets from the 2D layout drawing reduce dependencies on CAD software and reduce error in layout planning.

Flexsim represents only the active layout sheet as floor plan not all the sheets in the layout drawing file. But, in 3DS multiple sheets of 2D layout drawing can be imported (figure-16). This helps layout design engineer in greater extent by eliminating the dependencies on external design software. On the other hand, flexsim import all the data in the active sheet irrespective of the selection of the active window in the layout sheet. The active window is the area that is specified as the plot area. But in 3DS software, the imported 2D layout displays information pertains only to the active window. For instance, if a blank area is fixed as an active window in CAD software, the imported drawing represents nothing. Since the main objective of this research is to eliminate layout modifications the awareness about prerequisites eliminate error and reduce layout design-time required. Also, increasing the number of prerequisites indicate software incompetence's which can result with inaccurate layout design. Thus, comparing both the software prerequisites as mentioned in table below from 2D to 3D, 3DS is simpler than Flexsim. Also, the dedicated design application '2D layout for 3D design', '2D layout design insights' are the major reason to prefer this software for layout planning. Due to integrated and dedicated layout design application for layout design, the creation of a 2D layout and altering the existing 2D layout can also be achieved using this 3DS software. This eliminates dependencies on traditional 2D CAD software for design and modifications.



Factors	Flexsim	Dassault
Importance of Unit selection	✓	✓
Auto CAD format (.dwg, .dxf)	✓	✓
Support recent version of Auto CAD(2018)	☒	✓
Import data from inactive window in the layout drawing	✓	☒
Import multiple sheets	☒	✓
Import with layout annotations	✓	✓
Edit layout drawing feature	☒	✓

Figure 16: Factors differentiating 3DS and Flexsim in layout planning

The main objective of converting layout design from 2D to 3D and 3D to 2D is to integrate layout used for both project planning and implementation. Because the 3D layout is used in layout planning phase and 2D layout are used for implementation phase considering the resource limitations in the shop floor. Hence, lack of synchronisation between this two-stage leads to use of non-updated layout which increases the layout alterations. The main reason for the use of non-updated layout is because of traditional tools will not support synchronised 2D and 3D layout design. Similarly, the flexsim will not support this requirement of converting 3D layout to 2D and synchoronised layout planning due to lack of inbuilt design application. But, dedicated designing application for layout design in 3DS support synchronised layout planning in both 3D and 2D. The feature called 'CATIA Graphical Representation' (CGR) in 3DS helps to convert the 3D into 2D. The robotic kiting cell layout 3D is converted into 2D Drawing depicting three different views viz., Front, Top and Side view as shown in figure-17.

The conversion of 3D kitting cell layout to 2D depicting three different views is achieved only by using three mouse clicks. The creation of multiple views using traditional 2D CAD software is more difficult and requires hundreds of mouse clicks. The layout drawing in 3D and different views in 2D help to identify the dimensional and positional risk of designed layout. Identification of risk in the planning phase reduce the effort and also cost for layout modifications. For instance, the robot leg collides with the fence pillar is identified using this feature. Since, risk identified in the planning phase before implementation, the layout is modified accordingly in the virtual environment. This identification of risk in virtual environment reduces layout modification and cost of rectification. This verification of layout design in the virtual environment also helps to reduce the layout implementation lead time which is one of the major problems for manufacturers.

In addition, in-built design and dedicated layout planning '2D layout for 3D design' application in 3DS enable the designer to annotate the converted 2D layout with dimension and associated details. This reduces duplication of work by importing the 2D drawing into CAD software. This feature reduces time and risk of data loss during data translation. Even though, flexsim being novel software for 3D design, lack of a feature to convert 3D to 2D is one of the biggest drawbacks to use flexsim for layout design. Therefore, this case study indicates that the conversion of the 2D layout to 3D can be achieved in both the software with certain prerequisites, but the conversion of the 3D layout to 2D can be achieved only by using 3DS, not through flexsim. The synchronised 3D and 2D layout planning with the aid of integrated 2D layout for 3D design, CATIA drafting applications in 3DS ensure use of updated layout in manufacturing which reduces planning error and eliminate layout modifications. Hence, considering the unique feature of 3DS and its benefits in layout planning, it is more appropriate to use 3DS than using flexsim for layout design.

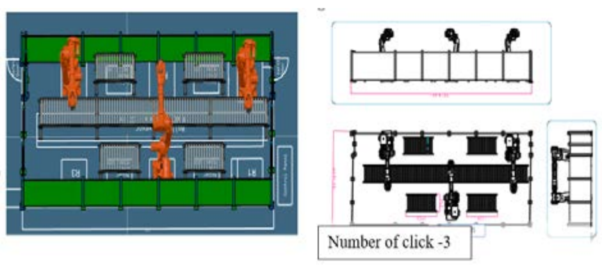


Figure 17: 3D to 2D conversion in 3DS

b) Examining the capabilities to integrate different 3D model data format

Consolidation and integration of 3D models from the different department for factory layout design is the major challenge for all manufactures. Because different stakeholders use different 'CAx' software for the creation of a model (Shariatzadeh *et al.*, 2012a). The data compatible with the different file format and the standard model data exchange formats STEP, IGES are still challenging for manufacturers. Since flexsim is not an integrated design application, it supports only certain file format as listed in table-8. It indicates that it supports all the standard data exchange format and commonly used model data formats. Similarly, 3DS being integrated design application it also supports both standard data exchange formats and commonly used model data formats. However, using this case study the data compatible feature for standard data exchange formats is analysed using robotic kitting cell layout planning. A STEP (.stp) file of trolley designed using external (PTC) modelling software is imported in both the software to understand the practical complications.

.3ds	.ac	.ase	.blend	.cob	.csm	.dwg	.dxf	.hmp	.igs	.irr	.irrmesh	.lvo	.lvs
.mod	.ms3d	.obj	.ply	.q3o	.q3s	.raw	.scn	.skp	.stl	.stp	.wrl	.xml	.zgl

Frequently used by manufacturers

Table 8: File formats supported in Flexsim

Despite, the STEP file format is one of the supporting file formats of flexsim. The representation of the imported model does not reflect the actual spatial representation as indicated in figure-18a. This is mainly due to data loss during data translation. Then, the .stp file format is converted to another flexsim supported file format .ac3D using external conversion software and the converted file is imported in flexsim to achieve the exact spatial representation. This data translation increases design lead time by increasing the number of clicks required to import model designed by different software. It also increases complexity to manufacturers by increasing the dependence of using a standalone software for data conversion.

But, in 3DS due to the integrated design application, the import STEP file represents the actual model. In addition, it also enables to edit the design parameters of the model using the inbuilt modelling applications viz., part design, part assembly etc., Whereas flexsim requires re-importing the 3D models for every small modification. Also, the accuracy of the imported model is not ensured in flexsim due to data translation which leads to the use of an incomplete model for layout planning. The use of an incomplete model leads to a planning error which requires layout modifications during implementation. Therefore, considering the drawbacks of flexsim, it is recommended using 3DS for layout planning. Hence, this case study helps to conclude that 3DS is more appropriate than flexsim considering the following benefits viz., reduced design lead time, reduced number of clicks, reduced dependability of external software, accurate representation of standard data model(.stp) and dedicated design application that support modifying the imported 3D model parameters.

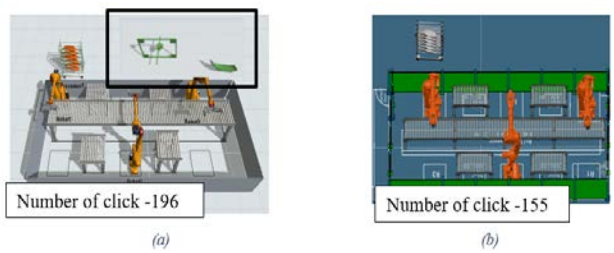


Figure 18: Importing a trolley model (.stp) (a) Flexsim (b) 3DS

c) Examining capabilities for collaborative design and data management

Layout planning is a multidisciplinary process which requires collaboration and coordination between multiple departments for factory level layout planning. Factory-level layout planning includes the integration of multiple cell-level layouts. Also, analysis of factory level layout involves both kinematic and discrete event simulation. According to theory, integration of both kinematic and process discrete event simulation using

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the same software does not exist and yet to be established (Ackermann *et al.*, 2013).Similarly, Flexsim supports only discrete event simulation, not a kinematic simulation. Despite, flexsim support basic kinematic changes in the resource model, it is not suitable for kinematic analysis. But, 3DS promotes that being an integrated product lifecycle management (PLM) tool, it can integrate both kinematic and discrete event simulation. Since it is the secondary data from the software publisher, the collaboration feature is evaluated in this case study.

This case study is to examine the use of 3DS software for factory level layout design that comprises two different cell layouts viz., robot kitting cell and assembly cell.

Firstly, the robot kitting cell layout planning initiate with the positioning of robot and facilities based on a 2D floor plan using 'Plant layout design' application of DELMIA product in 3DS. Then, the kinematic behaviour of the robot is analysed using the 'Robot simulation' application by DELMIA. The robot simulation application help to create tag points for kitting robot, define robot parameter settings viz., motor speed, rotation speed, home position setting as per the industry standard in the virtual environment. After defining all the input, the kinematic analysis helps to analyse the robot motion in the designed layout. It helps to analyse the robot arm reach zones and support to identify collisions during robot kinematic movement as shown in figure-19.

This analysis of risk in the virtual environment before implementation reduce layout implementation lead time through eliminating the need of layout modifications. The risk mitigation involves both positional and functional changes in the robot. However, the change in the position of robot impact layout design and in traditional standalone layout planning tools the changes will not get reflected. But in 3DS, since both the plant layout design and the robot simulation are supported by the common product 'DELMIA' and uses an integrated product data management, changes in one application reflect on the other. Since robot kitting analysis and layout analysis is performed by two different departments in a manufacturing industry. This collaborative planning feature reduces duplication of work and improves planning accuracy by the use of consistent and coherent data. The improved layout planning accuracy achieved through collaborative planning reduce layout modifications.

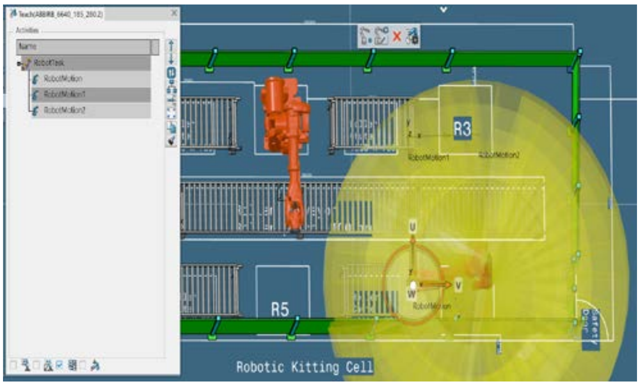

Figure 19: Reachability zone being shown in 3DS

Secondly, the use of process simulation in manufacturing industries to optimise the process and improve productivity is becoming more common. The productivity changes in the process require modification in the layout. Lack of integration between the process simulation and the layout simulation leads to layout planning error which is identified only during the project implementation phase. This error increases the number of alterations in the layout in the manufacturing industry. For instance, in this case, the assembly planning process simulation from the targeted industry is analysed. The main objective of assembly planning engineer simulation is to improve process efficiency which requires facility position modifications. The existing facility positions decided by the layout planning engineer is to achieve space utilization. Since both the engineers use two different non-integrated tools for layout planning, the changes will not reflect and creates more layout alterations during implementation.

3DS being the collaborative tool it supports both process simulation and layout simulation using the applications of DELMIA and CATIA products. Because 3DS integrate Product, process, Resource (PPR) in the common platform that supports factory level layout planning. The product is designed and defined using part design, part assembly applications of CATIA. The assembly process incorporating the part bill of material, process sequence and creation of manufacturing bill of material (MBOM) is defined using 'manufacturing item definition' application by DELMIA. The manufacturing resources involved in the assembly process is designed in 3D using 'Plant layout design' application. Later, the assembly process production parameters viz., cycle time, MTBF, MTTR, resource allocation, resource balancing and improved process utilization of the process is defined using 'process planning' and 'planning structure' applications of DELMIA in 3DS. After defining all the inputs, the output viz., manufacturing Gantt chart, workload balancing and resource balancing dashboards as shown in figure-20, support process engineer to optimise the utilisation of process and resources.

The 'process flow simulation' support process planning engineer to optimise the process based on the simulation output and it also helps to mitigate the risk, identify bottlenecks involved in the process planning before implementation. The changes related to the process and resource also reflect in the plant layout due to integrated planning and collaborative data management. On the other hand, the assembly process involves an input of kitting from the robotic kitting cell. Thus, both the process simulation and robot simulation must be integrated to analyse the factory flow and to design an optimised layout design.

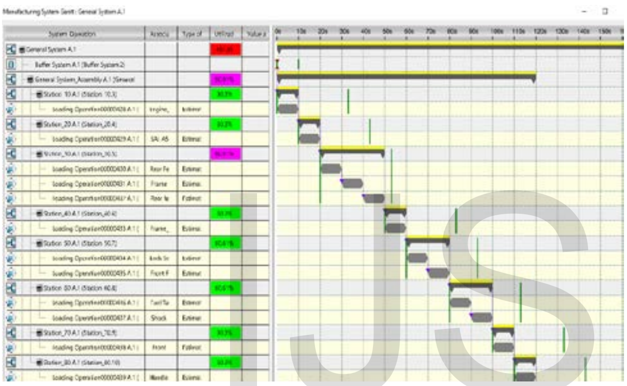

Figure 20: Example of Gantt chart

Finally, the 'factory flow simulation' application in 3DS helps to integrate both kinematic and DES. This integration is achieved because the manufacturing simulation product DELMIA is integrated into common platform 3DS. In DELMIA the product, process and resource are integrated with common product data management, therefore any changes in manufacturing product also reflect on both process and resources and vice versa. In this case study, to examine the integration feature in factory flow simulation application, the robot simulation with kinematic analysis and the assembly layout with process analysis is integrated. As shown in figure-21, both the kinematic and process simulation is integrated using the factory flow simulation application.

In addition, it also supports manufacturers to analyse the entire manufacturing system which involves multiple processes. The different level in simulation support manufacturer to analyse the designed layout in different aspects. The basic discrete event simulation focusses only on events in the manufacturing system. The dynamic level 1 simulation integrate Kinematically and DES. The dynamic level 2 simulation integrate kinematic, human movement and DES. The selection of appropriate simulation level is as indicated in figure below. The performance output through this analysis support manufacturer to analyse as system level than analysing individual levels. This unique feature in 3DS ensures data integrity and continuity which support layout planning engineers to plan an accurate layout that eliminates modifications.

Figure 21: Integration of kinematics and process simulation in 3DS

d)Examining ease of use

The manufacturing industry focuses more on the software ease of use feature than the technical features. Because complex software design not only increases the training requirement but also increases the design lead time. Since, the objective of the research focussed only on layout design, examining the ease of use in both the software is also restricted only to the layout design. The definition of ease of use varies from industry to industry based on the purpose and software use. In theory, the measure of ease of use is more subjective where the impact cannot be quantified. But, in this case study, the number of mouse clicks is used as the measure to quantify the effort required to create different manufacturing scenario's in both the software.

Spatial representation of bin using flexsim is simpler than 3DS, due to the use of basic shape from libraries. Also, the unique drag and drop options in flexsim reduce the number of mouse clicks. Similarly, in the creation of robotic kitting cell layout by using models from the library requires a minimum number of mouse clicks in flexsim as indicated in figure-18. But the parametric design of the customized 3D model is difficult to design using flexsim. This is due to the lack of integrated modelling applications.

3DS being an integrated platform, it is accurate in representing different standard data formats and the number of mouse clicks required to import different data format is also lesser than flexsim. Since manufacturing layout planning involves a different model with different file format designed by various departments and suppliers, considering data compatible benefits 3DS is more appropriate for layout design. In addition, the accurate representation of the actual product as a digital model can be achieved using 3DS, but not using flexsim. The accurate representation improves accuracy in layout planning and reduces alteration. Thus, comparing the intricate nature of layout planning, 3DS is more appropriate, easy to use for manufacturing layout planning than flexsim.

In modelling and simulation software, the accessibility to different tools within the software is also an important ease of use feature for manufacturers. Because modelling requires the use of different tools during 3D modelling and the frequency of use of different tools is also maximum. Therefore, ease of accessibility to the modelling tools in simulation software is also an evaluation criterion for manufacturers. For instance, the creation of an accurate model tree result with accurate 3D models. Integration of both model tree and modelling window in the same screen improve visibility and reduce error. But, in flexsim to modify the definition of a product in a model tree, it requires the designer to use different tabs as indicated in figure-a below. Since modelling tree and the modelling window are not integrated, for factory level layout planning which involves thousands of models, it leads to an error in layout planning .

Despite, 3DS being the collaborative platform that integrates hundreds of applications in the common platform, the structured and integrated arrangement of tool pane along with the modelling window is a unique feature of 3DS. Mainly, the 3DS model tree is integrated with window pane which eliminates the need for switching between multiple tabs and improve visibility. Also, using the same screen to access different windows is also possible through 3DS as shown in figure-22b below. On the other hand, selection of tool pane based on application is user specific in the 3DS until 2015 (V5). In 3DS 2017x, 'action bar' in the bottom of the modelling screen contains a set of applications which varies automatically based on application. This ensures ease of accessibility to a different tool and becomes more user-friendly designing environment.

In addition, the importance of navigation pointer or compass also influences easy to use the feature. Because it facilitates designer for accurate positioning, rotation and modification the model in the third axis. Flexsim navigation pointer is not user-friendly. Because, the pointer in flexsim support only linear modifications and not angular modifications as indicated in figure 25, it requires specified angle to be entered in the quick properties window for angular modification. Whereas in 3DS through a six-axis robotic navigation tool (robot) as indicated with an arrow in figure below, it supports both linear and angular modifications. Lack of six-axis tool for navigation in flexsim requires 20% more click or keyboard input to define the position. The intense of this increased 20% click will be magnified in factory-level modelling which involves hundreds of models. Also, there is a chance of positional inaccuracy which impacts layout planning. Inaccurate position in layout increases the number of layout alterations. Thus, considering all the features 3DS is user friendly and easy to use software than flexsim for layout planning.

Figure 22: Model tree (a) Flexsim (b) 3DS

8.3 Case study 3- Investigation of integrated 3D modelling and simulation features

In this case study, 2D layout from the company 'x' is converted to 3D parametric layout model using 3DS. The objective of this case study is to understand the capabilities to integrate both modelling and simulation in common platform to eliminate the data loss during translation. Because traditional practice requires external manufacturing simulator to integrate spatial model and simulation. During translation using the external simulator, the chance of data loss is high and lead to import incomplete data model. The use of incomplete data or functional model result with layout modifications. Thus, this case study focusses on software competence to integrate modelling and simulation. Since flexsim will not support modelling, only 3DS is used in the entire case study for analysis. A systematic approach using three steps is adopted to examine the integration competence of the software

a) Conceptual Modelling

The half of the estimated benefits through simulation can be achieved only by creating an exact conceptual model. Because the result of the simulation depends on the conceptual model accuracy and the conceptual modelling designer must aware of the end-end process before designing a model. The design involves dealing with more data from a different department, a systematic approach is followed to collect and correlate information for conceptual modelling. Thus, Robinson (2004) framework for modelling and simulation is adopted in this case study. It comprises five steps viz., Understanding the problem situation, determining the project objectives, identifying the model inputs, identifying the model outputs and determining the model content which also includes certain assumptions. Since the first two stages are already discussed in detail in initial sections, identification of model input and output drives to achieve the project objective.

Since the project focus on eliminating layout modifications during volume ramp up or new product introduction in the manufacturing industry. The output that contributes to reducing current layout modifications and its related input is also identified. After finalising the input and output, the level of detail involved in the model must be defined, because a model with a minimum level of details leads to inaccurate or biased decisions and too much of detailing increase difficulty in modelling. Both lead to inaccurate layout planning and result in layout modifications. In addition, it also consumes more time for modelling with more details which increases the overall layout design lead time. Hence, more than input and output identification, finalising the level of detailing in both input and output is more important for 3D modelling and simulation (Law & Kelton, 2007).

The model input and output identification help to understand the boundaries of the model whereas the level of detail helps to understand the technical data involved in the model. The entire manufacturing factory-level layout design and simulation require more time which is more difficult to develop within the project timeline. Because the modelling also includes self-learning and exploring the software by the researcher only with the aid of online tutorials. In addition, an online tutorial for the factory layout design and simulation is very minimum. Hence, understanding the constraints the project scope is defined only to the manufacturing assembly layout planning integrating two assembly cells.

The simulation models of assembly layout are developed using four types of components viz., entities, activities, queues and resources. Although there is a different type of components proposed by different authors for simulation and modelling, only with this basic four types of component major discrete event simulation model can be created. Also, there is no restriction to add additional components in the later stage of model design (Melão & Pidd, 2006). Thus, the list of components involved in the assembly layout planning is identified and the purpose for inclusion or exclusion in the model is also listed in table-9 (Tako & Robinson, 2010).

List of components	Include/Exclude in modelling	Justification	Level of detail
Entities			
Engine	Include	To analyse the throughput of engines to estimate queue length	1. Quantity produced 2. Arrival rate
Vehicle	Include	To analyse the throughput of the vehicle to estimate queue length	1. Quantity produced 2. Arrival rate
Tools /Subcomponents	Exclude	The objective is on layout optimisation not on the process	NA
Activities			
Engine Assembly conveyor (Schematic)	Include	Conveyor influence throughput	1. Conveyor speed 2. Breakdown /repair time 3. Setup /Change over
Vehicle Assembly conveyor (Schematic)	Include	Conveyor influence throughput	1. Conveyor speed 2. Breakdown /repair time 3. Setup /Change over
Subassembly conveyor	Exclude	The objective is on layout optimization not on the process	NA
Assembly Part feeding conveyor	Exclude	The focus is on product queue length estimation	NA
Queues			
Pallets	Include	To represent queue and to understand the queueing behaviour	1. Queue capacity 2. Queue Behaviour
Engine Trolleys	Include	Experimental factor. Also, to calculate the number of trolley requirement based on queue length	1. Storage capacity 2. Queue behaviour
Resources			
Operator	Include	Required for transferring parts from queue	1. Transfer time as per IE recommendations
Maintenance staff	Exclude	Focus is on product queue length estimation only, including failure rate is sufficient.	NA

Table 9: Purpose for inclusion or exclusion of a component

After identification of a list of components, three steps to be adopted to complete modelling and simulation. It includes process mapping, logic flow diagram and activity cycle diagram (Robinson, 2004). Process mapping helps the designer to understand the flow of the process. Since the main objective of the project is on layout design, the process flow of assembly layout planning is as illustrated in figure-23a below. It involves two assembly process represented in the box and two queues which are represented in a circle. Likewise, the logic involved in the assembly layout planning process is as depicted in figure-b below. The logic diagram improves visualisation of the process and indicates the importance of queue in layout planning process. Hence, the major focus of this experimentation is on queueing at discrete time events.

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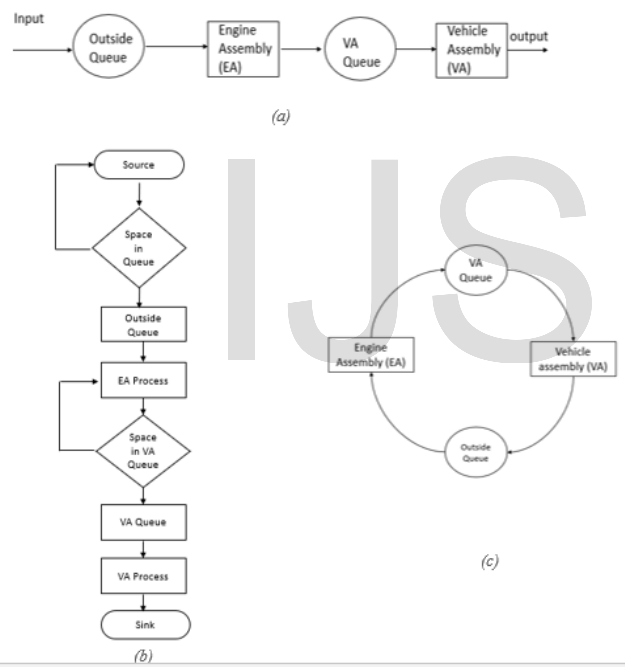


Figure 23: Assembly planning flow chart models

The specific means of the model that support discrete event simulation is represented using an activity cycle diagram. As indicated in the activity diagram of assembly layout planning in figure-23c, any changes in the engine assembly and vehicle assembly which is an active state have an impact on queueing. The change in the queue due to process change impact layout design and leads to layout modification. The biggest drawback of existing layout planning tools is the lack of a feature to understand the dynamic behaviour of queueing. The static analysis of queue result with inaccurate area estimation and results leads to two extreme conditions viz., excess area allocation or area shortfall. Thus, the area estimation based on the dynamic behaviour of queueing is the important requirement for manufacturers in layout planning process to improve area estimation accuracy and reduce modifications (Negahban & Smith, 2014).

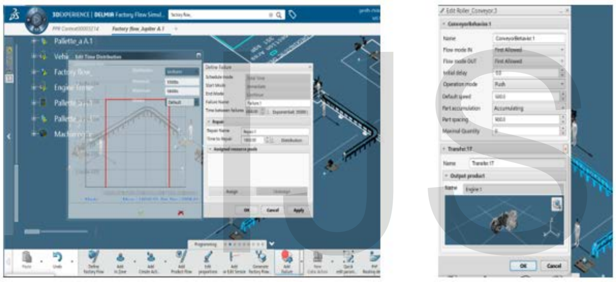
b) Model creation and definition

Firstly, the 2D layout is used as a footprint for 3D layout design using 'Plant layout design' application in 3DS software. The standard elements involved in the layout design viz., conveyors, pallets are used from the existing parametric designed resource libraries and it is customised based on the requirement. The user-defined resources viz., trolley, products 3D model (.stp format) collected from the company 'x' is imported and positioned in the layout. Since the objective of this case study is on dynamic analysis and not on the visual representation, the level of detailing to 3D modelling is very minimum. Thus, through minimal approximation, the model 3D layout representing the assembly planning process as shown in figure-24 is created with reference to the process planning map.

Figure 24: 3D layout of assembly process

Secondly, the process parameters collected as secondary data viz, conveyor speed, process time and the arrival rate from the targeted company is also incorporated in the model. Since dealing with a mathematical equation to define product arrival rate with statistical distribution is more complex and time-consuming process in the traditional layout planning software. This software enables the user to define the type of distribution which calculates the arrival rate input based on the distribution type. For instance, provision to define the mean time between failure (MTBF), mean time to repair (MTTR) of organisational resources viz., the conveyor is defined as shown in figure-25a below, which is not possible with the existing layout planning tools in 2D.

Despite, this feature reduces complexity in solving a mathematical equation, the use of improper statistical distribution type also leads to error. For instance, use of normal distribution for process simulation is not optimum, because time cannot be defined as negatively. Hence, the selection of statistical distribution is also important which requires basic knowledge of mathematics(Law & Kelton, 2007). In this case study, the parameters of conveyor behaviour viz., conveyor speed, default spacing between the part, initial part delay, accumulation is also defined as per the industrial requirements as shown in figure-25b. Since, the main objective is only on layout design and queueing, human associated with the queues and the IE recommended process timing for manual operation is used as input in the model for analysis. Similarly, the human ergonomics is not focussed much in this modelling because the IE recommendation includes all safe working practices. But, the facilities involved in this layout design is as per the industrial safety standard and safe ergonomic design conditions.



(a) (b)

Figure 25: Factory flow planning in 3DS

Finally, the flow of materials is assigned based on the logic flow diagram using the 'Factory flow simulation' application in 3DS. The flow between the system and the resources are created just by clicking on the resources, the chevron line and circle indicates the successful creation of flow between resources as shown in figure-26. Defining the queueing mode based on the process is an important factor in factory layout design and lack of attention to queueing mode leads to design failure. The selection of queueing mode from three types viz., First in First out (FIFO), Last in First out (LIFO), random arrival is also defined as depicted in figure-26 based on process logic flow diagram (Refer figure-25b). In addition, the queuing capacity, reorder level and the initial stock is also included as queueing properties. This helps to link the shop floor data during design to achieve accurate planning results. Also, through this centralised product and process data management, the dependency on standalone tools can be eliminated which is the prime problem for an increased layout design lead time. On the other hand, there are certain prerequisites to be known before the creation of flow between entities.

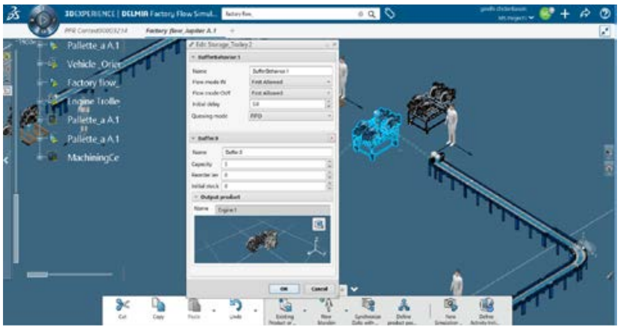


Figure 26: Inputs for process flow in 3DS

Secondly, the process parameters collected as secondary data viz, conveyor speed, process time and the arrival rate from the targeted company is also incorporated in the model. Since dealing with a mathematical equation to define product arrival rate with statistical distribution is more complex and time-consuming process in the traditional layout planning software. This software enables the user to define the type of distribution which calculates the arrival rate input based on the distribution type. For instance, provision to define the mean time between failure (MTBF), mean time to repair (MTTR) of organisational resources viz., the conveyor is defined, which is not possible with the existing layout planning tools in 2D.

Despite, this feature reduces complexity in solving a mathematical equation, the use of improper statistical distribution type also leads to error. For instance, use of normal distribution for process simulation is not optimum, because time cannot be defined as negatively. Hence, the selection of statistical distribution is also important which requires basic knowledge of mathematics(Law & Kelton, 2007). In this case study, the parameters of conveyor behaviour viz., conveyor speed, default spacing between the part, initial part delay, accumulation is also defined as per the industrial requirement as shown in figure-26. Since, the main objective is only on layout design and queueing, human associated with the queues and the IE recommended process timing for manual operation is used as input in the model for analysis. Similarly, the human ergonomics is not focussed much in this modelling because the IE recommendation includes all safe working practices. But, the facilities involved in this layout design is as per the industrial safety standard and safe ergonomic design conditions.

Finally, the flow of materials is assigned based on the logic flow diagram using the 'Factory flow simulation' application in 3DS. The flow between the system and the resources are created just by clicking on the resources, the chevron line and circle indicates the successful creation of flow between resources. Defining the queueing mode based on the process is an important factor in factory layout design and lack of attention to queueing mode leads to design failure. The selection of queueing mode from three types viz., First in First out (FIFO), Last in First out (LIFO), random arrival is also defined based on process logic flow diagram. In addition, the queuing capacity, reorder level and the initial stock is also included as queueing properties. This helps to link the shop floor data during design to achieve accurate planning results. Also, through this centralised product and process data management, the dependency on standalone tools can be eliminated which is the prime problem for an increased layout design lead time. On the other hand, there are certain prerequisites to be known before the creation of flow between entities.

Specifically, the awareness about resource definition and the type of resource selection reduce the flow creation lead time. Error in the resource definition restricts product flow. For instance, defining the conveyor under the 'storage' category restricts product movement and flow. Because storage is non-working resource whereas conveyor is a working resource and the product will not move in the storage category. Thus, the designer must aware of available resource categories in the software as shown in table-10. Despite the name of the resource definitions vary between software but the condition remains the same. Hence, to define the flow between resources based on the logic diagram, use of suitable resource definition is also an important factor to be considered to reduce error.

S.no	Resource	Category	S.no	Resource	Category
1	Area	Organisational	8	Control device	Working
2	Robot	Working	9	Logic controller	Working
3	Worker	Working	10	Storage	Non-Working
4	Transport	Working	11	Tool Device	Non-Working
5	Conveyor	Working	12	Sensor	Non-Working
6	NC Machine	Working	13	User-Defined	Non-Working
7	Inspect	Working	14	Manufacturing setup	Non-Working

Table 10: Resource categories available in software

Correspondingly, Factory level layout planning involves thousands of resources and error in flow creation leads to inaccurate analysis results. The use of inaccurate simulation leads to inaccurate layout planning decision which require modification in layout during implementation. On the other hand, the time required to identify the error and the type of error in modelling consume more time. However, factory flow application in 3DS provides information about the flow creation using business intelligence essential 'BI essential' tool. The correct, incorrect, possible error and not used resources in the designed layout are highlighted using green, red, yellow and white. In addition, it also suggests solutions for the identified error to correct the incorrect definition which helps layout designer to resolve the issues very quickly. The BI essential tool in 3DS helps to improve the accuracy of resource definition.

As shown in figure-27, the error in the definition of the queue is due to incorrect selection of product in the queue. By clicking on the error, the tool also suggests that the product is used in the entire flow as indicated by an arrow. The information from the software helps to improve the accuracy of the system. Hence, BI essential feature help to improve the accuracy of defined product flow in simulation and support accurate decision making.

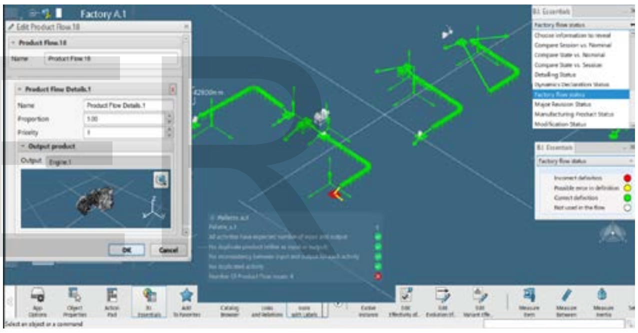


Figure 27: Errors being shown in BI essentials

b) Discrete event simulation and experimentation

Theory suggests that the business process model requires a simulator or translator to convert engineering models into the business process model (BPM) to execute simulation in discrete time events. The transition is achieved through external manufacturing simulator which converts the CAD, CAE model into XML process definition language incorporating all the data in the model to run DES. This conversion of engineering model viz., layouts to a business model with all material, information flows consumes more time and chance for data loss is also high during the transition. In addition, information flow is unidirectional and there is no feedback from the system can be used as input to improve the system performance(Fishman, 2013; Tako & Robinson, 2010). The unidirectional information flow restricts feedback from the system and unidentified error result with layout modifications. Hence, through 3DS the feature to integrate both the engineering model and the business model that support layout planning is examined using the same case study with assembly layout planning.

Discrete event simulation helps manufacturing industries to analyze the performance of the system through experiments. A different set of experiments can be performed using the same 3D model only by modifying the input or model's logic. Each experiment consists of one or more replications (trial). The number of replications also impact the accuracy of the results. Generally, the manufacturers focus on a steady-state analysis where the output will not vary with respect to initial conditions. Therefore, the results during the warmup period should not be considered for analysis. Although each replication uses the same set of input data and the model logic, output data varies because of own unique set of random numbers generated through software programming. The theory also suggests that random number will not repeat until 10^30 iterations. This helps to analyse the system and extract data that support statistical analysis (Law & Kelton, 2007).

The defined assembly 3D model is simulated to understand the hourly output and queueing behaviour. The same logic and same set of input data are used for five independent replications. The five replications dynamic queueing output based on simulation for the designed assembly layout is as shown in table-11. Since queue has a major impact on layout design in an assembly planning process, the estimated queue length through simulation is used as the base value for area estimation. Also, it is evident through this experiment that 3DS does not require any simulator to convert the engineering models to achieve business performance output. Because the same CAE model designed using the 3DS software is used for DES. Hence, through this dynamic analysis, the integration of both the engineering model and the business model feature is examined using 3DS. This unique feature in 3DS support manufacturers to reduce error in area estimation which reduce the layout modifications in the manufacturing industry.

Replications	Hourly output			Queue 1	Queue 2
	EA	VA	Test		
R1	329	408	348	79	60
R2	329	408	348	79	60
R3	329	407	348	78	59
R4	329	408	348	79	60
R5	329	408	348	79	60
Total	1645	2039	348	394	299
Average	329	408	348	79	60
Takt time	28	33	44		

Table 11: Hourly output data of assembly simulation

Specifically, in this case study, the performance measures of the system viz., resource utilization, idle time, inventory level etc., of the designed layout support manufacturer to improve the performance of the system based on the output. Also, this improvisation support manufacturer to design an optimum layout. According to theory, traditional layout planning calculates the inventory of the system based on the static analysis assuming that the product flow is constant. With that principle, the static analysis to maintain hourly stock results storing 120 engines as inventory. But through dynamic analysis achieved through simulation of assembly planning process, the inventory required to maintain one-hour stock is only 79 which reduce the inventory requirement by 34%. Also, the static analysis does not include the actual production parameters whereas dynamic analysis includes all the production parameters viz., cycle time, failure rate, arrival rate etc., with a statistical distribution. This improves the accuracy of layout planning process and reduces modifications. Thus, through dynamic analysis of layout design, the area estimation accuracy is also improved which is one of the major problems in the manufacturing industry and the targeted industry.

Since the main objective of the project is to eliminate layout modifications during new product and volume ramp-up projects using simulation. The dynamic analysis output (queue length) of the assembly planning process is interlinked with the area estimation process to improve estmation accuracy. This improved accuracy in area estimation support manufacturers to reduce layout modification during new project or volume ramp up. The use of modelling and simulation for layout analysis than using mathematical algorithms improves layout planning accuracy. Also, the modelling and simulation analysis for factory level layout planning is not as difficult as solving mathematical algorithms. However, the requirement of mathematical algorithms is not completely eliminated through the adoption of simulation techniques. Because the dynamic analysis output through simulation shows only queue length, which is actually a number. It will not convey any information without using mathematical algorithms. With that output, the layout design engineer cannot get any dimensional input to design a layout. The conversion of simulation output to dimensional input requires simple mathematical algorithms. The algorithm includes an equation for the area estimation which includes material handling dimensions of the queue.

The equation support manufacturers to convert the simulation output into the dimensional input. It is used to estimate the cell level queueing area requirement of both engine assembly and vehicle assembly from the queue length achieved through the discrete event simulation as shown in table 3. The cumulative sum of the individual cell level area supports manufacturers to attain factory level area estimation. The basic area calculation rule l x b is used to estimate the required area from the queue length. From the estimated area, the dimensional input for block layout design is also derived with the use of queueing material handling dimensions. For engine assembly, the source of the queue is in the trolley and for the vehicle assembly source of the queue is vehicles. On the other hand, the dimensional input varies based on the arrangement of MHF. Since the arrangement of MHF varies from designer to designer, a template as shown in table-12 is demonstrated to get a quick dimensional input length & width based on the arrangement. This use of analysis tool like spreadsheet reduces calculation complications for layout design engineer.

Despite, the layout analysis uses mathematical algorithms (Equations, template) to interpret the dimensional input from the simulation output, this is distinct from the traditional use of algorithms. The traditional method uses algorithms for the entire layout analysis assuming all the production parameters are static. But here the algorithms are used only to interpret the simulation results that are achieved through dynamic analysis of layout using computer modelling and simulation. Hence, the using an equation or algorithm to interpret result from the dynamic analysis will not impact on accuracy and leads to error.

$$Z_1 = A_1 x_1$$

$$Z_2 = A_2 x_2$$

$$Z_t = Z_1 + Z_2 \ldots + Z_{n-1} + Z_n$$

Where,

Z_1 = *Area required for Engine assembly cell*

A_1 = *Material handling facility sotrage footprint area* ($l\,X b$)

x_1 = *Queue length of engine assembly line through simulation*

Z_2 = *Area required for Vehicle assembly cell*

A_2 = *Material handling facility sotrage footprint area* ($l\,X b$)

x_2 = *Queue length of vehicle assembly line through simulation*

Z_t = *Total Area required*

Template

Cells	L (in m)	W (in m)	Area (Z)	Queue (X)	Area Reqd	MHF
EA	1.4	1	1.4	79	111	13
VA	2	0.6	1.2	64	77	64

Queue 1- Dimensional input

No of trolley	1	2	3	4	5	6	7	8	9
Width (in m)	79	40	26	20	16	13	11	10	9
Length (in m)	1.4	2.8	4.2	5.6	7	8.4	9.8	11.2	12.6
Total Area	111	111	111	111	111	111	111	111	111

Queue 2 -Dimensional Input

No of Vehicle	1	2	3	4	5	6	7	8	9
Width (in m)	38	19	13	10	8	6	5	5	4
Length (in m)	2	4	6	8	10	12	14	16	18
Total Area	77	77	77	77	77	77	77	77	77

Table 12: Template for layout analysis

On the other hand, the improved accuracy in layout estimation also helps to reduce the material handling cost. Because this calculation also supports to estimate the required material handling facility for the defined assembly process based on queueing. Since the dynamic analysis of layout reduces the inventory by 34%, it also contributes to reducing the requirement of MHF. Since MHF contributes for 65 % of total manufacturing cost any reduction in material handling facility benefits manufacturers to reduce the overall manufacturing cost. Hence, this case study about factory layout modelling and discrete event simulation of layout design using 3DS has four major benefits:

- The visualisation is improved because of 3D layout design.
- Use of the same software for modelling and simulation reduce error, layout modification, layout design lead time, dependencies on the external simulator.

- Dynamic analysis through DES help to improve area estimation accuracy
- Integrated layout planning and material handling facility planning reduce manufacturing cost and improve planning accuracy.

9. Implication of research

9.1 From Case study 1

The objective of the first case study is to examine the spatial representation and parametric design capabilities of both the simulation software. The design of the plastic bin and a kitting bin is considered in this case study. The result indicates that flexsim is capable of representing only the basic shapes viz plastic bin, not the customised models like kitting bin. This is due to the lack of integrated modelling applications. But in 3DS, because of an integrated design platform comprising of different applications from CATIA viz., natural shape, part design, part assembly, natural sketch support achieving accurate spatial representation. This is examined and demonstrated using the design of kitting bin. Even though, flexsim being novel 3D manufacturing simulation software, lack of modelling feature requires external design software to import customised 3D models to achieve desired dimensional accuracy. Since handling of two software systems increases maintenance cost and training cost for manufacturers and the chance of model data loss during model translation from design software to flexsim is also high. Thus, ***an accurate spatial representation can be achieved only by using 3DS, not through Flexsim.***

On the other hand, the competence of the parametric modelling feature in both the software systems is also compared and examined in this case study. In 3DS, due to the integrated design application, the parametric design can also be achieved by defining the parameters of the model during the design phase. Despite, it requires additional effort (Increased number of mouse clicks) to create a parametric model, it is negligible considering the time required to create a model from zero. The design of steel mezzanine is used to illustrate this feature using 3DS. Different type can also be defined in 3DS as design table, through which only by mentioning the type the design parameters will get modified. This parametric design and advanced design table feature cannot be achieved using flexsim due to lack of integrated design application. Only basic shapes and basic 3D model form the library can be modified using the quick properties window in Flexsim. Thus, evidence from this case studies helps to conclude that ***3DS support parametric design feature of any model whereas flexsim support parametric feature only for basic 3D models in the library.***

9.2. From Case study 2

The second case study examines both the software with four different factors that support manufacturing layout planning. A robotic kitting cell layout from the targeted industry is used for examining all the factors in this case study. Firstly, the competence to convert 2D layout drawing to 3D and 3D layout to 2D were analysed in this case study. Result suggests that both the software is competent to build a 3D layout from 2D design. However, the dedicated application in 3DS viz., 2D layout for 3D design and 2D layout insight from CATIA product support layout design engineer to import 2D, annotate using the same application. This reduces an inter-dependency between CAD software and also reduce data interaction complexity. Even in flexsim the 2D layout drawing can be imported,but cannot be modified or annotate due to lack of integrated design feature. Through this case study, it is also demonstrated that the number of prerequisites to import 2D layout drawing in flexsim is higher than 3DS.

The capability of the software to convert the 3D layout to 2D, to eliminate the problem of using non-updated layout during implementation is also analysed in this case study. It is found that the flexsim is not competent to convert 3D layout to 2D , whereas 3DS using CATIA 'CGR' tool it is competent to support synchronized 2D and 3D layout planning. The conversion of robotic kitting cell from 3D to three different views in 2D is achieved using only three mouse clicks. Thus, ***3DS is recommended for manufacturing layout planning witnessing the unique feature of synchronised 2D and 3D layout planning***. This finding also benefits the targeted industry to eliminate the use of non-updated layout.

Secondly, the data compatible with the standard product data exchange format STEP was analysed in this case study. It is examined by analysing the competence of both the software to import a trolley file in STEP (.stp) format into the robotic kitting cell layout. It is found that flexsim is not competent to import STEP file and the imported file spatial representation is not the actual. This happens mainly due to the data loss during file translation. Despite, STEP is mentioned as one of the supporting formats of flexsim (Refer table 12), it is not competent to import the file format without data loss. This data loss during data translation leads to use of incomplete data model in layout planning which leads to error. Then, the majorly supporting format of flexsim .ac3D format, the trolley model is converted from .stp format to .ac3D format using external conversion software to achieve the exact spatial representation. Lack of feature to support standard data format and requiring external conversion software for importing different 3D format are the major drawbacks of flexsim which is identified through this case study. In that aspect, 3DS import and represent the actual representation of the trolley in a .stp format without the requirement of any external conversion software. Also, the integrated tool also comprises of inbuilt conversion software that converts different data format to the required format without depending on the external software. In addition, the imported 3D model can also be modified in 3DS which cannot be done using flexsim. Thus, ***considering the drawbacks of flexsim in data compatible capabilities as demonstrated in this case study, 3DS is recommended to use for manufacturing layout planning.***

Thirdly, a collaboration of kinematic and layout simulation was examined in this case study using kitting cell layout planning. Result suggests that flexsim support only DES, not a kinematic simulation. Despite, flexsim support kinematic manipulation of the robot in 3D, it is not competent to analyse the kinematic behaviour of the robot. But in 3DS using DELMIA 'Plant layout design' the resources like conveyors and robot involved in robotic kitting cell layout is created in 3D using existing models from the library. The competence to create tag points for kitting robot, robot path analysis, robot arm reach zone, robot collision detection is also demonstrated in this case study. Later, the dynamic behaviour of the robot is analysed using 'Robot simualtion' application. Since both the applications 'robot simulation' and 'plant layout design' of DELMIA integrated through common platform 3DS, the change in one application reflects on the other. This improves duplication of work and ensures use of consistent and coherent data which improves layout planning accuracy. Thus, ***through this case study, it is demonstrated that the 3DS is competent to integrate both kinematic and layout simulation. Also, collaboration improves layout planning accuracy by using coherent and consistent data through planning.***

The integration of kinematic simulation and discrete event simulation, one of the major requirements of manufacturers was also investigated in this case study. The integration of assembly process layout planning and robotic kitting cell layout planning is used in this case study to illustrate this feature. The dedicated applications of DELMIA viz., manufacturing item definition, plant layout design, process planning, process flow simulation support process engineers to design a 3D layout, define and optimise the process using 3DS. In addition, the integration of process discrete event simulation and kinematic simulation achieved using 'factory flow simulation' application by DELMIA. This support manufacture to analyse layout as a manufacturing system than as individual cells. Also, integration of kinematic and DES is a unique feature that supports manufacturers to improve layout planning accuracy by eliminating data translation. This finding also supports manufacturers to reduce dependencies on standalone software and support fact-based decision through integrated planning. Thus, through this case study, ***it is evident that 3DS is competent to integrate kinematic and layout, kinematic and discrete event simulation using DELMIA applications.***

Finally, the ease of use feature which is a major requirement for manufacturers to adopt simulation for layout planning is analysed in this case study. Despite, theory suggests that flexsim is easy to use and designed for manufacturing, through this case study it is demonstrated that it is appropriate only for basic modelling with limited geometrical constraints not for customised modelling with exact geometrical representation. This is also demonstrated in this case study using a number of mouse clicks as a measure to quantify ease of use (Table-13). Flexsim is easy to create a layout with the basic shape and layout design that comprises a basic model from the library. But, in all other customised model creation 3DS requires a minimum number of clicks than flexsim. This is mainly due to integrated design and data management. Since factory level layout planning involves more customised model, using 3DS effort (the number of clicks) will be reduced by 26-30 %. The easy to access different tool in the 3DS software viz., model tree, six-axis robot and the user-friendly graphic interface are better in 3DS than flexsim. Considering the key feature of 3DS, it is illustrated that 3DS is easier than flexsim for layout planning. Thus, through this case study, ***it is proven that 3DS is better than flexsim for layout planning in the following aspects viz., data compatible, collaborative planning and ease of use.***

Figure Number	Context	Number of mouse Clicks	
		Flexsim	3DS
17	Spatial representation of bin	9	36
20	Kitting cell layout 2D - 3D	106	142
23	Kitting layout with customised 3D model	196	155

Table 13: Summary of number of clicks used to create different manufacturing scenarios

9.3 From Case study 3

The third case study objective is to investigate the competence of integrating modelling and DES using the same software. Because theory suggests that it requires an external simulator to convert modelling data function into simulation data format. It is found that flexsim is not suitable for integrating both modelling and simulation software because of its standalone nature. But, in 3DS through integrated product data management (PDM), the product, process and the resource (PPR) level are integrated. It is also demonstrated in this case study by creating the 3D model of two assembly cells viz., engine assembly and vehicle assembly. The same engineering model is used for the simulation in 3DS to analyse the dynamic behaviour of queueing and integrate with layout planning. the same CAx model developed using 3DS is used for DES without any external simulator for translation.

In this case study, the designed layout is analysed using the same data and logic for five independent replications to understand the queue length of the system. Since queueing impact on layout design. The queue length result from simulations is correlated with area estimation process to improve accuracy. But to convert the simulation output into the dimensional input, a mathematical algorithm (equation) is used to estimate the area from the estimated queue length and distinct of using a mathematical algorithm from traditional practices is also demonstrated. The estimated area using that equation is compared with traditional static analysis of layout which results with 34 % reduced inventory. In addition, based on the estimated area, a template to calculate the dimensional input for block layout design based on material handling dimensions of the queue is also demonstrated in this case study. The purpose of the template is mainly to eliminate the mathematical error which leads to increase layout modifications. Through this case study, integrated layout and material handling facility planning that support manufacturers to reduce MH cost are also demonstrated. Therefore, ***the integration of modelling and simulation using common software reduce data translation loss. Also, the integration of dynamic analysis output with area estimation reduce both error in area estimation and the manufacturing cost***. Thus, 3DS is unique in several aspects and support manufacturers to overcome the problem that exists in manufacturing layout planning through the integrated platform that combines design, manufacturing and data management. The correlation of identified layout problems with case study objectives and achieved results are summarised in table-14.

Case study	Objectives	Demonstrated with	Gaps in current layout planning tools to create a 3D layout design	Data compatible issue	Lack of collaborative layout design feature	Lack of importance dynamic behaviour	Lack of Integration between 3D modelling and simulation	Layout modification decisions are based on expert's knowledge not based on facts.	Traditional layout planning process requires more time to implement an engineering change (EC)
1	Compare spatial representation and parametric design features	Kitting Bin Steel Mezzanine	3DS Flexsim						
2	Examining data compatible, collaborative planning and ease of use feature	Robotic kitting cell layout and Assembly process planning layout		3DS Flexsim	3DS Flexsim	3DS Flexsim			3DS Flexsim
3	Investigation of integrated 3D modelling and simulation features	Engine assembly and Vehicle assembly schematic model					3DS Flexsim	3DS Flexsim	

XXX Complete solution
XXX Partially eliminate the problem
XXX Not suitable

Table 14: Research objectives and its achievements

10. Conclusion

The purpose of this research is to eliminate layout modification during volume ramp-up or new product introduction (NPI) using 3D simulation. Through literature, it is found that the problems that exist in current layout planning process and tools are the major causes for layout modification in the manufacturing industry. The significance of the problem is verified through data triangulation where the primary data and secondary data from the manufacturing company 'X' is compared and correlated with literature findings. This data traingulation helps to conclude that, seven identified problems in current layout planning process and tools create significant impact. Therefore, the selection of simulation software is based on software capabilities to overcome the identified problems. The available DES and layout simulation software systems identified using literature are evaluated based on ranking method. Two simualtion software viz., 3DS by Dassault systems and flexsim were identifed to overcome the current layout planning problems. Then, to verify the software capabiltities through exploratory analysis, three different case studies from the targeted industry were examined. The results and findings from the case studies indicate that, dedicated applications in 3DS, support manufacturers to eliminate the current layout planning problems. Despite, Flexsim being novel 3D software, it is not competent to solve all the identified layout planning problems.

By consolidating all the findings and the learnings from this research, a framework to use simulation for layout planning is proposed. With this, all the four objectives of the research are achieved. The aim of this framework is to support manufacturers to eliminate layout modification using 3D simulation. This framework addresses most of the problems that exist in traditional layout planning process and tools. Firstly, the problem of using a sequential approach which increases the number of iterations in layout planning, is reduced by using a concurrent planning approach. The decision for layout modification in the traditional planning process is based on expert's knowledge, and not based on facts. But, in the proposed framework using layout simulation, the performance of the designed layout modifications is validated with required performance measures that support management for fact-based decisions. This helps to reduce erroneous layout planning decisions, through which the modifications in layout can be eliminated.

Similarly, use of limited data and static analysis of layout for area estimation leads to error in layout planning. Thus, the proposed framework using 3D simulation tool supports manufacturers to analyze the dynamic behaviour of layout, incorporating all production parameters with a statistical distribution. Also, the output from dynamic analysis is also interlinked with area estimation process to improve planning accuracy. A simple algorithm to convert simulation output into layout design input is also proposed and demonstrated in this research. Through this research, it is proven that all the significant layout planning problems can be eliminated by using the proposed framework and the simulation tool '3DS'. However, this proposed framework requires validation through implementation to improve reliability. Implementation of a new idea in manufacturing with the structured framework ensures systematic planning and eliminate confusions. Thus, the proposed framework can be used as a guideline for manufacturing industries to use 3D simulation for layout planning to eliminate layout modifications.

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