APPLICATION OF DIGITAL PROCESS SIMULATION ON AN AUTOMOTIVE PRODUCTION LINE

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ABSTRACT

This paper presents the work on the development of a digital simulation model for the transportation line in a local automotive manufacturing plant. It describes a structured procedure of data collection, digital design, model building, activity creation, and process simulation using simulation tool Delmia. Based on the digital simulation model, new alternative concepts of production line planning strategy can be easily integrated into the model to evaluate the cycle time/cost and to optimise the production line. The demonstration result indicates that digital simulation can be used as a powerful tool to reduce planning risk, identify material flow bottlenecks, and to improve throughput and knowledge share within the company.

Keywords: Digital simulation; Production line; Cycle time; Delmia

1. INTRODUCTION

Innovative information tools and digital technology have been widely used in manufacturing systems to shorten the product development cycle, integrate enterprise modelling, and to improve outbound logistics (Lee, 2000). To predict the material and information flow and evaluate alternative strategies in a short time during the early planning and design phase, a manufacturing system simulator is often used as a support tool to simulate the fabrication and assembly of any product, including the associated manufacturing processes prior to actual production (Hibino *et al.*, 1999). It thus helps manufacturers to develop high quality products fast, economically, and with a high level of adaptability (Offodile and Abdel-Malek, 2002).

Delmia as a subsidiary of Dassault Systèmes is one of the most comprehensive and integrated digital manufacturing solutions for process-centric customers (Dassault Systèmes, 2005). Its application as a manufacturing system simulator to improve production efficiency and quality, and reduce cost and market response time, has been investigated by many researchers. Thornton (2001) describes how Lockheed Martin used Delmia to simplify and speed up routine maintenance tasks for the next-generation joint strike fighter. Chan (2003) presented the work on developing simulation models with Delmia using the same product data source for analyses in the virtual environment of various manufacturing activities including product development, production planning, assembly analysis, work study, workplace design, operation simulation and plant layout. Connolly (2006) investigated the capabilities, features and applications of the Delmia robotic simulation package in the nuclear and other industries. He gave a detailed description of the procedure for modelling the robot and its workspace, defining its movements, interacting multiple robots and integrating with other aspects of the manufacturing process such as product flow and resource utilisation.

The object of this study, therefore, is to investigate the application of digital simulation in the early design and planning phase of manufacturing system. The transportation line between the body shop and paint shop of an automotive manufacturer was studied as an example to describe the process of building a digital simulation model and developing an alternative planning concept for the production line.

2. DIGITAL SIMULATION

Using digital simulation, the real process can be visualised to identify the bottlenecks of material flow, and alternative concepts can be evaluated in order to optimise the process and improve the throughput. In this study, a procedure consisting of three steps was used to develop a digital simulation model, as illustrated in Figure 1.

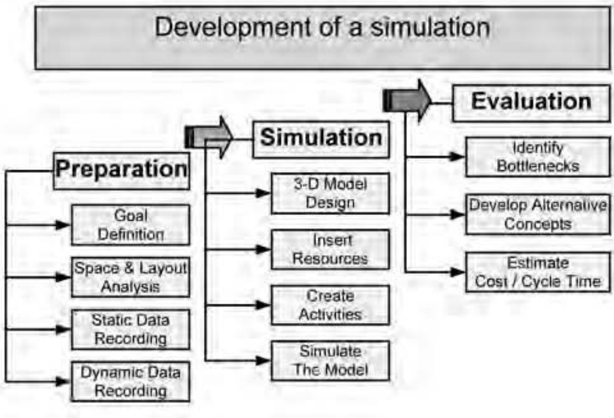


Figure 1: Procedure of digital process simulation

Preparation A clear goal is set to define which production section in the manufacturing plant is to be simulated by analysing the cycle time/down time. Thereafter, the shop space and the resource layout of the production section are recorded in order to build a simulation room containing all resources and products. Static data such as the geometric dimension of resources and products are recorded. Dynamic data such as process steps and cycle times are also recorded in the preparation phase.

Simulation After having recorded all necessary information of the production section, the simulation room is built using the space/layout data. The 3D digital model for each resource and product is then inserted into the simulation room. Activities are created to simulate process steps with pre-recorded information such as distance, speed, and cycle time. The whole manufacturing process can be simulated after correctly ordering the activity sequences.

Evaluation When simulating the current process, bottlenecks in the process can be visualised and digitally analysed. Alternative concepts with regard to layout alternatives, machine exploitations, and process steps can be easily developed and integrated into the digital simulation model to remove process bottlenecks. The new concepts are then evaluated based on the analysis of cycle time and cost to determine the optimal solution of planning.

3. A CASE STUDY - PART 1: DIGITAL SIMULATION MODEL BUILDING

In this study, the transportation line between the body shop and the paint shop of a local automotive manufacturing plant is investigated.

3.1. Background of the transportation line

The white bodies from three production lines (line A on the first floor, lines B and C on the ground floor) are transported from body shop to paint shop. All white bodies from the three lines are moved by the hoists and their jigs and loaded onto the skids, which are returned from the assembly line and distributed by the skid elevator. The white bodies and skids are then moved by manual trolleys to the main conveyor, where they are uploaded by main elevator from ground floor to first floor. After that the white bodies and skids are transported to the paint shop by the automatic conveyor on the first floor.

3.2. Digital process simulation tool

The simulation software Delmia is used in this study as a simulation tool. It allows manufacturers to virtually define, plan, create, monitor and control all production processes. Its Digital Process for Manufacturing (DPM) family enables users to define a process by creating hierarchies of operations and sequencing those operations (Dassault Systèmes, 2005). The Assembly Process Simulation (APS) workbench of the DPM family allows users to develop process plans with simulations that describe activities for products and resources over time. Once the alternative concepts are developed, the built-in functionality can be used to compare the concepts and find the most efficient and cost-saving alternatives (Dassault Systèmes, 2005).

3.3. Construct the digital process model

To build the digital process model for the transportation line, only components which are relevant to the process simulation are considered. Necessary data such as geometric dimensions, process steps, cycle times and layout measurements are recorded on line. All components are inserted into the simulation room according to their recorded orientation and location in the workshop.

3.3.1. Resource and product design

The digital design of the component is simplified in a way that it only needs to represent the essential dimension and function of its real counterpart. In this study, all simulation components are divided into two groups: products that are used to create the end-result of a process (car body), and resources that are required during the process itself (trolleys, hoists, conveyors, etc.). The Part Design and the Assembly Design workbenches of Delmia are mainly used for the construction and assembly of the resources and products to be simulated (Dassault Systèmes, 2005).

Figure 2 gives a picture of the trolley and its digital model. The trolley is used for loading, unloading, and transporting the white body between different conveyor lines. The final digital model consists of eight parts. The rotating of the two wheel pairs and the motions of the four pistons in the cylinders make possible the forward/backward movement of the trolley as well as the up/down movement of the trolley table.

Figure 2: The trolley and its digital model

3.3.2. Integrating all resources and products to build the static model

In the DPM APS Workbench, the process model is initially built as a static model, in which the time is not relevant and only one instant of the simulation is taken. The simulation room, consisting of the outer walls, floor, roof, and elevator fences, is inserted first into the ResourceList of the Products, Processes and Resources (PPR) tree to limit the available room of the simulation. All digital resources and products are then loaded into the ProductList and ResourceList branches of the PPR tree (Dassault Systèmes, 2005).

The locations of the resources and products in the simulation room can be done with the layout tool snapping function in the DPM APS Workbench. Using the predefined frames on the object and the target position, the object can be moved towards the target position by snapping its frame to the frame of the target position. Figure 3 illustrates the trolley being snapped into position between two conveyors.

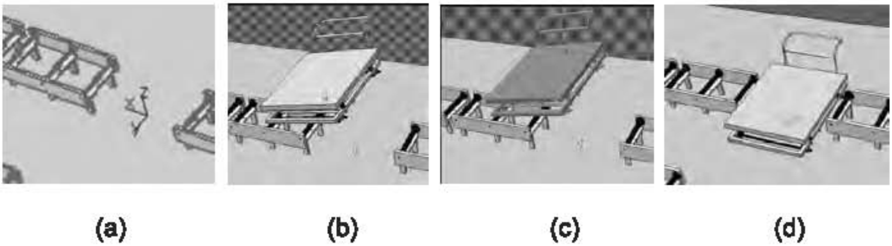


Figure 3: Trolley location using snapping function: (a) frame on target position; (b) trolley inserted with initial position; (c) frame on trolley selected, and (d) trolley snapped to target position.

After all resources and products are loaded into the PPR tree, the first static digital process model is built for further simulation. Figure 4 illustrates the static process model for the transportation line. Table 1 lists the resources and products used in the transportation line process model.

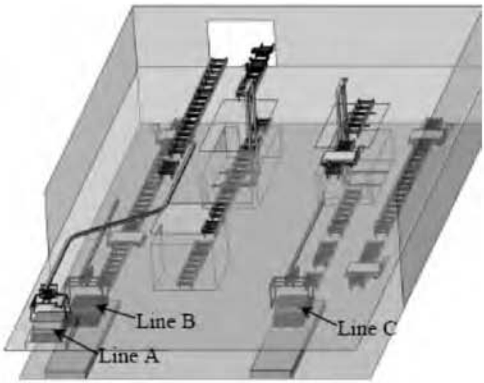


Figure 4: Finished static process model

Table 1: Resources and products in the model

Resources & Products	Quantity
Simulation room	1
Hoist system with jig	3
Conveyor section	35
Elevator	2
Trolley	5
Skid	3
Car body	3

3.4. Simulation of a dynamic model

In a dynamic simulation, time is the main aspect. To develop a process taking into account the workflow and cycle times, motion activities are assigned to the mobile products and resources in the static model. Furthermore, these activities are ordered in such a way as to reproduce the real motions in the production line.

3.4.1. Create activities for the mobile components

The main dynamics concerned in this case study are white body/skid movements. Motion activities of the resources such as trolleys, elevators and hoists are created with the recorded cycle time and track in order to accurately transport the white body/skid.

Using the DPM APS Workbench's powerful part motion trajectory generation technology, the following activities are created in this study to move a part in a desired trajectory (Dassault Systèmes, 2005):

- Movement activity
- Device activity
- Grab/Release activity

A movement activity is created by commanding the mobile part to move through a series of positions in accurate sequence and time (Dassault Systèmes, 2005). Both simple and complex motion trajectories can be defined using frames on the part and its location point in the simulation room. Figure 5 illustrates the movement activity being created for the trolley to move from one conveyor line to next conveyor line.

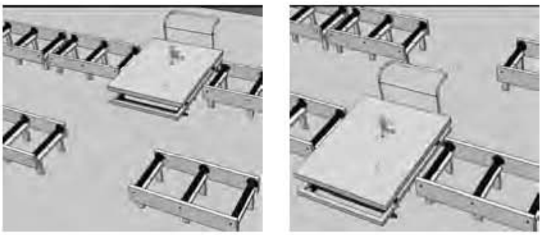


Figure 5: Track of the movement

A device activity is created when the movement of the device is complicated whereas the mechanism of the device is known. Delmia's Device Building Workbench is used in this study for modelling forward-kinematic mechanical devices that can be driven in joint coordinates. A simple way to create a device activity is to command the mobile part to move between pre-devised home positions in accurate time (Dassault Systèmes, 2005). Figure 6 illustrates the hoist jig on line A opening/closing its arms with the link mechanism for releasing/grabbing the white body.

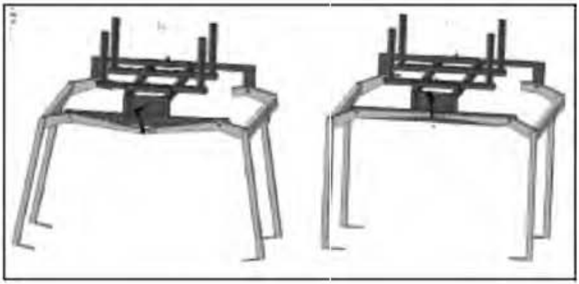


Figure 6: Line A hoist jig arms open/closed

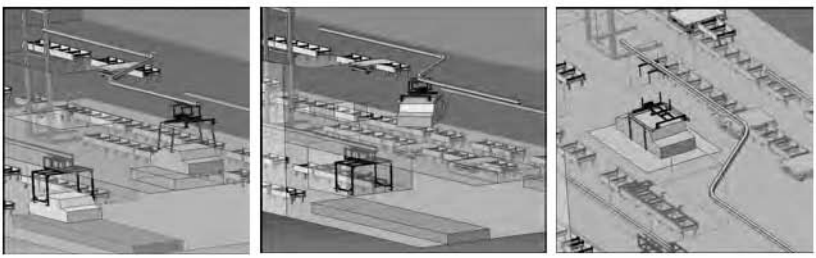
A grab activity is created to make one object move with another until a release activity executes. For example, when the hoist jig moves to a white body and closes its arms, the white body is grabbed by the jig and moves with the jig on the rail until it is released on the conveyor.

3.4.2. Order the activity sequences

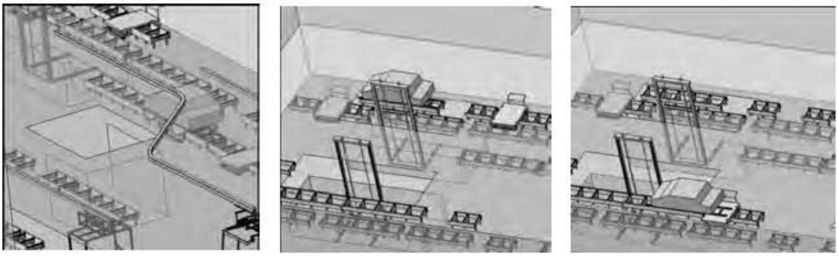
After all activities are created, they are reordered to reflect the real process sequences. With the help of the PERT Chart tool, the created activities are ordered serially or parallel within a process and therefore execute serially or parallel.

3.4.3. Run the simulation

Once an activity or a whole process is created, it can be run, and its animation can be viewed in the Delmia simulation environment. Figure 7 (a) to (f) gives the example of the 3D animation of the transportation process of the white body from line A at different time in the simulation.



(a) (b) (c)



(d) (e) (f)

Figure 7: Snapshots of line A white body transportation: (a) gripped by hoist jig; (b) moving on hoist rail; (c) moving downstairs; (d) moving to main conveyor; (e) lifted upstairs by main elevator; and (f) moving to paint shop.

3.4.1. Analyse the cycle times

After running the simulation model, only the cycle times on the ground floor for each production line are compared, as the transportation on the first floor is the same for each line. The cycle times are divided into four categories: hoist transportation, conveyor transportation, trolley transportation, and main elevator transportation. Figure 8 gives the cycle times for the four production lines. It can be seen that compared to lines B and C, the transportation time of line A is much longer, owing to the fact that line A ends on the first floor: the white body from line A has to be transported downstairs to the main conveyor, and then transported to the first floor again by the main elevator.

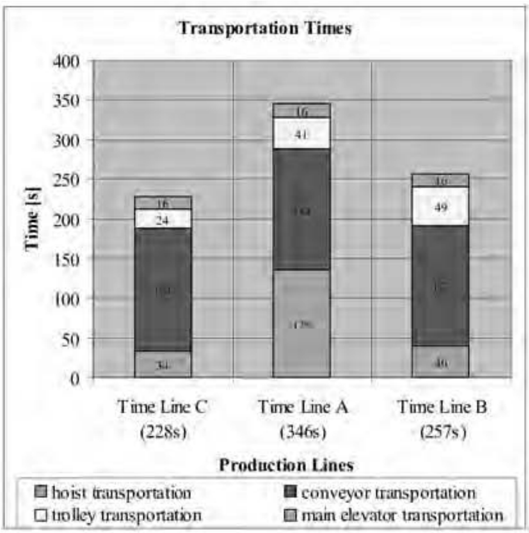


Figure 8: Cycle times of the three production lines

4. A CASE STUDY - PART 2: ALTERNATIVE CONCEPT DEVELOPING AND EVALUATING

After running the first simulation model, the bottlenecks in the process are visualised and identified. Alternative concepts are therefore sought and incorporated directly into the current simulation model to eliminate the bottlenecks in the process. The alternative concepts are further evaluated and compared to the current model in terms of cycle time, cost, safety issue, etc.

4.1. Main focus: weak points and presumptions

By analysing the simulation results, bottlenecks in the transportation lines are identified as the main focus for alternative concept development. Through the analysis of cycle time, work load, and safety issues, the following targets are identified for new concept:

- Reduce the cycle times, especially of line A, by changing white body/skid transportation route.
- Reduce the workloads of the main elevator and the skid elevator by reassigning white body and skid transportation tasks for each elevator.
- Improve the safety in the path located between lines B and C for people to go through by eliminating the trolleys' moving across.

For the development of new concepts there are certain presumptions made regarding resources and costs. Generally the new concepts should be planned with already-used resources like the conveyor, trolley and hoist engineering systems. Furthermore the room of the transportation line is limited and won't be expanded for a new concept. Finally, some manual engineering systems can be replaced by alternative automated systems on condition that they are feasible and justified in terms of cost and productivity.

4.2. Present the concept

As described in previous section, the main aspect of the new concept is to reduce the cycle times, especially of line A, and to relieve the bottleneck in the area of the main elevator and skid elevator.

A new concept for the transportation line is developed on the basis of the existing simulation model. The transportation routes of the white bodies from the three production lines are all changed, in order to reduce the cycle times and improve safety. Some resources in the current model are removed while additional resources are incorporated. Figure 9 illustrates the new concept simulation model.

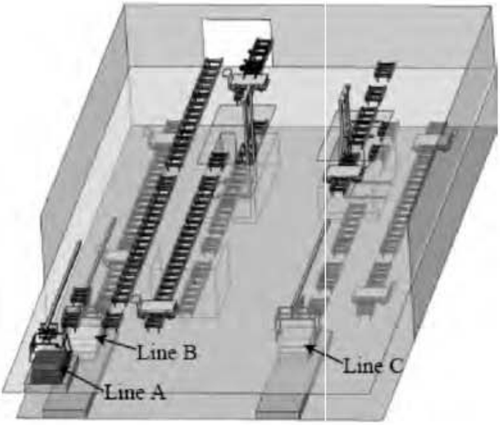


Figure 9: Alternative concept model

4.2.1. Changes made

Compared to the current model, a few changes have been made in the new concept, including:

- moving the whole transportation process of line A to the first floor;
- using the skid elevator for both the skid and white body transportation of line B;
- using the main elevator for both the skid and white body transportation of line C.

As a result, two additional conveyor sections and a trolley are added on the first floor for the transportation of white bodies from line A and the skids. For line C, one additional conveyor section is placed on the ground floor to receive skids downloaded from the main elevator, while another conveyor section, together with a trolley, is added on first floor to move skids returned from the assembly line to the main elevator. There is no equipment change for line B except that white bodies from line B are now lifted upstairs by the skid elevator instead of being moved across the path to the main elevator.

4.3. Evaluation of the concept

After running the simulation of the concept model, its cycle times, work loads and safety issues are compared to those of the current process.

4.3.1. Cycle times

Figure 10 shows the white body transportation times of the current process in comparison to those of the concept model.

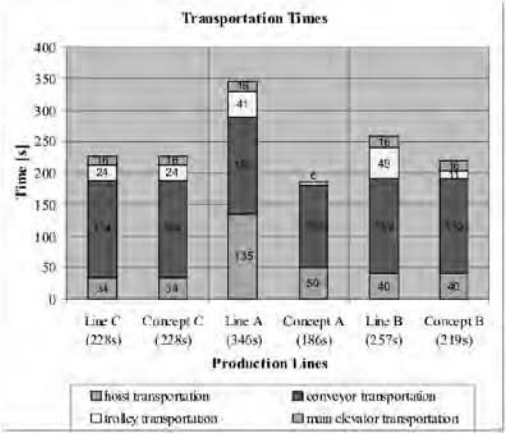


Figure 10: Comparison of cycle times between concept model and current line.

It can be seen that the transportation time of line A is reduced by almost 50%, as the long distance and slow transportation between the first floor and the ground floor is replaced by faster and shorter transportation on the first floor.

The cycle time of line B transportation is also reduced by shorter trolley transportation on both the ground floor and first floor, as the whole transportation of line B is now within the left side of the workshop instead of crossing the path to the other side. Possible delay time is also reduced as the trolley on the ground floor is now only used for line B, instead of both lines A and B.

4.3.2. Workload of main/skid elevator

In the concept model, the skid elevator is used for downloading skids and uploading white bodies for line B, while the main elevator is used for downloading skids and uploading white bodies for line C. For line A, both the uploading of white body and downloading of skid are eliminated. As the assignments for the two elevators are changed, their workloads are reduced.

Table 2 gives the total workloads of the two elevators in the new concept compared to those of the current process using the volume data between 7 and 10 April 2008 for analysis. It can be seen that the total workload of the two elevators can be reduced by approximately 200 times per day.

Table 2: The workload of main/skid elevator

	Line A Current	Line A	Line C	Line C	Line B	Line B
Volume*	95	95	200	200	207	207
Times of skid elevator using	1	0	1	0	1	2
Times of main elevator using	1	0	1	2	1	0

* Average volume between 7-10, Apr, 2008 is used for analysis

	Current	Concept
Total times of skid elevator using	95*1+200*1+207*1=502	207*2 =414
Total times of main elevator using	95*1+200*1+207*1=502	200*2=400
Total	1004	814

In fact the usage of the main/skid elevator is also optimised in the new concept. In current process, the main elevator and the skid elevator are used only for uploading white body and downloading skid, respectively, which indicates that an empty return trip for each elevator is wasted. However in the new concept, for both elevators, with each uploading of one white body, there can possibly be a downloading of one skid on the return trip. This can further reduce the overall cycle times for the three lines.

4.3.3. Safety issues

In current transportation process, trolleys are moving across the path which is also used by workers, causing a potential safety risk in the workshop. With the new concept the trolley movement for the individual production line is restricted to one side; therefore, the new concept can greatly improve the safety in the transportation line.

4.3.4. Further discussion

With the new logistic methods in the new concept, the three transportation lines become more independent of each other. In fact this greatly relieves the potential bottlenecks with the heavy traffic on current transportation line, i.e. if the main elevator fails all three transportation lines will be stopped.

Another advantage of the new concept is that the whole transportation process can be implemented with different automation levels by using automated trolleys and conveyor systems similar to those on the first floor in current process.

5. CONCLUSION

The wide range of application and the benefits of digital simulation as planning tool have shown the great potential to the industry. In this study the construction of a digital simulation model using the simulation software Delmia is described with the example of a transportation section between body shop and paint shop production lines at Volkswagen South Africa. After identifying the bottlenecks in the simulation model of current process, a new concept was developed and integrated into the simulation model. As demonstrated in this example of concept development, alternative scenarios can be found quickly and incorporated directly into the simulation model to relieve the bottlenecks, to reduce the cycle times, to optimise equipment usage, and to improve safety. It is therefore concluded that digital simulation can be used to save on planning time, to avoid serious decision faults and thus to save on costs.

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