Simulation Model for Evaluating Scenarios in Painting Tasks Scheduling in the Automotive Industry

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Keywords: Simulation, Scheduling, Automotive Industry.

Abstract

The aim of this paper is to show some of the benefits of using simulation to analyze manufacturing processes, particularly those related to tasks scheduling in a paint plant in the automotive industry. Simulation can provide information about a manufacturing process because a discrete event simulation model can capture both the variability and interdependencies of system elements. We can identify four levels of planning activities: 1. Aggregate Sales and Operations Planning, 2. Aggregate Operations Planning, 3. Master production Plan and, 4. Task Scheduling.
It is in this fourth level where priority rules are used in tasks sequencing.
This paper shows a case study about an important car manufacturer's Paint Shop. We built a model in Promodel 6.0 in order to test different priority rules in scheduling painting tasks.

I. Introduction

This work is based on Miquel Angel Piera's team work about the use of simulation tools applied to manufacturing [1]. The present paper takes up a case, emphasizing the Paint Shop and built a simulation model in Promodel 6.0. The main objective is to analyze how different rules of scheduling painting tasks impact the entire system performance.

Section two shows some aspects that justify the use of simulation instead of using optimization models. In section three we will see the four levels of planning activities:

- Aggregate Sales and Operations Planning.
- Aggregate Operations Planning
- The master Production Plan
- Tasks Scheduling.

Section four describes the general operation of the plant and the fifth section describes the construction of the simulation model.

2. Simulation And Optimization

Traditional Operations Research (OR) techniques use mathematical models to solve problems involving simple or moderately complex relationships. These techniques solve deterministic and mathematical programming models, routing problems or network problems. They also solve probabilistic models such as queuing theory and decision trees. The Operations Research techniques generate quantitative results quickly without using trial and error methods. These techniques can be divided into two types: prescriptive and descriptive.

OR prescriptive techniques provide an optimal solution to a problem. These techniques include both linear and dynamic programming. They are generally applied when the only objective is to maximize or minimize a cost function.
If a system requires considering secondary objectives related to maximization or minimization, OR techniques can handle it, but the mathematical difficulty increases. Additionally, these techniques do not allow the use of random variables.

Descriptive techniques such as queuing theory provide a good estimate for basic problems like finding the expected average number of entities in a queue, or the average waiting time in it. However, when the system becomes moderately complex, the model becomes very complex and mathematically intractable. In contrast, simulation provides estimates very close to the optimal figures for complex systems, and the simulation's statistical results are not limited to one or two metrics since they provide information on all performance measures over time. Simulation is a way to reproduce the conditions of a system using a model to study its dynamics to prove or predict their behavior.

Due to the fact that simulation runs in a compressed time window, weeks of operation can be simulated in minutes or even seconds. The features that make simulation a powerful tool in decision making can be summarized as follows:

- It captures system interdependencies.
- It handles Model variability.
- It is versatile enough to model any system.
- Shows the behavior over time.
- Simulation is less costly, time-consuming and invasive than experimenting directly on the studied system.
- It provides information of various performance measures.
- Simulation is visually attractive.
- Simulation runs in compressed time, real-time or even expanded time windows.
- It captures deep details of a design.

Simulation models create a system that acts as a substitute for the real system and the gained knowledge can be transferred back to the system.

Simulation has proven to be very effective in dealing with complex problems around manufacturing decisions. Since companies make vertical and horizontal integration aiming to improve the broad performance of the entire value chain, simulation is an essential tool for effective production planning and distribution processes.

Simulation in manufacturing systems covers a wide range of applications in different time horizons, including:

- Cells Administration (seconds).
- Task Scheduling (Hours).
- Load in Resources Studies (days).
- Production Planning (Weeks).
- Process Change Studies (Months).
- System Configuration (1-2 years).
- Technology Assessment (1-2 years).

If simulation is used to make decisions in the short term, it usually requires models to be more detailed and closer to actual operations, than those used to make long term decisions. Sometimes the model is an exact replica of the real system and it even reports the current system status; for example, control applications in real time and detailed planning systems of production. If simulation is used for making long term decisions, the models may or may not be similar to current operations. The model should not be very detailed because the high-level decisions about the future are made based upon fuzzy and uncertain data.

3. Task Scheduling

Scheduling operations is an activity that takes place as a result of alignment with the supply chain's planning.

The sales and operations planning processes culminate in a high-level meeting where key decisions are made for the medium term. The ultimate goal is to reach an agreement between the various departments about the best course of action to achieve an optimal balance between supply (Capacity) and demand. The idea is to align the operational plan with the business plan.

This balance must occur both at the aggregate level and at the single product level, so the goal in planning is to generate an aggregate operations plan for the areas of Manufacturing, Logistics and Services.

The Aggregated Operations Plan aims to establish production rates by product groups or another category in the medium term. The Master Production Plan comes from the Aggregated Operation Plan. The main purpose of the aggregate plan is to specify the optimal combination of production rate level of the workforce and inventory.
Aggregate Plan's shape varies with each company. In some places it is a formal report containing objectives and planning statements; in other companies, especially the small ones, the owner can perform simple calculations of the workforce needed.

The next level of the planning process is the Master Production Plan. This is a program containing times and specified tasks. It shows the detail of how and when each piece must be worked out. The aggregate plan for a manufacturing company should specify the total volume of a particular product that will produce the next month or quarter. The master plan takes the next step and identifies the features of the product such as its quality, color, size and style. The master plan also settles from period to period (usually on a weekly basis) how many particular products are needed and when.

The process of determining the production order in a machine or in a workplace is called sequencing or priorities sequencing. Priority rules are used for sequencing a task. Rules can be very simple and can be used for ordering only one figure like processing time, term date or arrival time. Other rules, although simple, require more data, usually to get an indicator, as the rule of the smaller time margin and the critical ratio rule.

Rule	DESCRIPTION
1. FCFS	*First-come, first-served*. Orders run in the order they arrive.
2. SOT	*Shortest operating time.* Run the job with the shortest completion time first. Often this rule is combined with a lateness rule to prevent jobs with longer times being delayed too long.
3. EDD	*Earliest due date first.* Run the job with the earliest due date first.
4. STR	*Slack time remaining*. This is calculated as the time remaining before the due date minus the processing time remaining. Orders with the shortest STR are run first.
5. STR/OP	*Slack time remaining per operation.* Orders with the shortest STR per number of operations are run first.
6. CR	*Critical rate.* This is calculated as the difference between the due date and the current date divided by the number of work days remaining. Orders with the smallest CR are run first.
7. LCFS	*Last-come, first-served.* This rule occurs frequently by default. As orders arrive, they are placed on the top of stack. The operator usually picks up the order on top to run first.
8. RANDOM	*Randm order or Whim*. The supervisors or operators usually select whichever job they feel like running.

Table 1. Priority Rules.

The following performance measures are used to evaluate priority rules:

- Due dates of customers or subsequent operations.
- Flow time.
- Work in process inventory.
- Idle time of machinery and labor.

4. Case Description

For this article's purposes the car manufacturing company's name was omitted. Also, no confidential information will be revealed.

Like many automobile manufacturing facilities, the plant begin studied is divided into three main plants: Body Shop, Paint Shop and Assembly (Trim & Chassis). There, four car models (A,B,C & D) are built.

4.1 Body Shop

In this section the main structure of the automobile is assembled. This process is achieved using three assembly lines as shown in Figure 1.

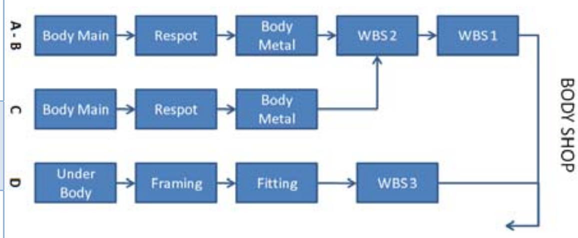

Figure 1. Body assembly lines.

There is one line for the D model and another line for C. A and B models, which are built in a shared single line.

To determine each of the sections that compound the Body Shop lines, different terminology is used. The equivalent processes are:

- Body main: Under body
- Respot: Framing
- Body metal: Fitting

In the Main and Under Body stations the bottom frame of vehicles is mounted. In

Respot or Framing stations the other structural parts are assembled. After having the entire skeleton ready, the vehicles pass through metal lines or Fitting in order to make little adjustments if needed. In this section, once the vehicle already has all its main parts, an ID is added to it in order to recognize the vehicle in the subsequent stations

Finally, vehicles go to stores WBS. In the case of the A model line, all vehicles are directed to WBS3, for the ET and HM lines, there are two stores.

WBS1, WBS2 and WBS3, represent the junction between Body Shop and Paint Shop. The first plant is responsible for filling the second plant buffers in order to pull vehicles along the marked sequence.

4.2 Paint Shop

The Paint Shop includes the paint plants P1 and P2. Both are located next to each other. This is important because part of the production line is worked out exclusively in P2. All vehicles at the beginning of the process must first pass through P2. Afterwards, some continue to P2, and the rest will be worked out in P1.

Figure 2 shows the flow of the vehicles in the Paint Shop. In P2 the initial phase of the painting process is located: the common P2. In this area a degreasing and washing process is made to the car body. Other various treatments are performed here too. All these processes are essential to each of the models produced at the plant. However, because they can be completed with some speed, they hardly become a bottleneck. All four models pass through the P2 Common.

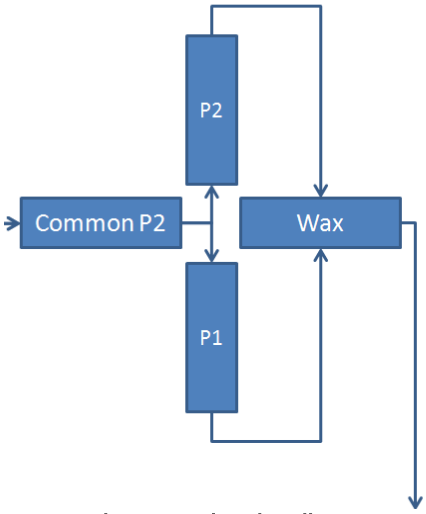

Figure 2. Paint Shop lines.

Once this initial process is made, some models are diverted to the plant P1 and others remain to finish the painting process in the plant P2. The A model must necessarily be diverted to the plant P1 because of its large volume. The other models produced can be painted in either of the two plants. However, the policy is to prioritize the work load of the plant P2. Once they reach the end of the processes P1 and P2, all vehicles are moved to the wax section. Finally the painted cars are transported to PBS stores. In this work we have used seven different colors: White, Gray, Silver, Red, Blue, Sandstone and Brown in order to

4.3 Trim & Chassis

The Paint Shop works two shifts a day. During this time they feed PBS stores for Trim & Chassis Shop. Paint and assembly lines have different speeds. Trim & Chassis Shop is working in parallel with all produced models and does not represent a bottleneck. For this reason, the Paint Shop's main objective is to produce a particular volume of vehicles for each of the models. This volume varies according to demand.

Figure 3 shows the Trim & Chassis Shop flow. There are three parallel lines where each body internal (Trim) and external (Chassis) parts are added. In this shop the lower body, the engine and main body are added.

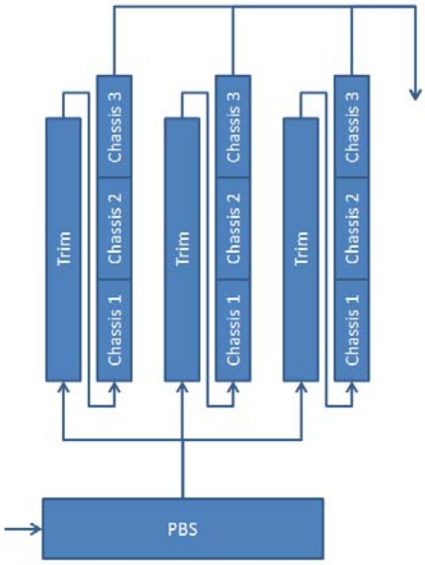

Figure 3. Trim & Chassis Shop

5. Model Design

In order to build a computer simulation model to describe the state and changes of the physical model, it is necessary to use some of the following elements: Locations, Entities, Routes, Resources, Processes, Arrivals and Variables.

Locations. They are fixed points in the system. They represent workstations or centers of attention. Its capacity is defined as the number of entities that can be addressed or processed.

Entities. They represent material, customers, documents or anything else that requires system resources to process. We have considered the four models A, B, C and D.

Routes. They represent paths from one location to another. They may represent roads, rows, or transport lines of material. The movement can be modeled in terms of time or in terms of speed and distance. Figure 4 shows the construction of the model.

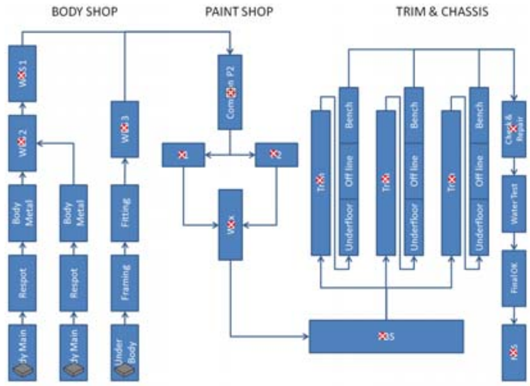

Figure 4. Model Construction.

Arrivals. The arrivals represent the first time an entity arrives to the system. In a simulation model, the time between arrivals is usually defined with a probability.

Processes. The process is defined for each entity arrival at each location, and may represent an operation or simply a timeout. In a computer simulation model, certain logic can be programmed to define the process.

Variables. Variables are reported as numerical values with relevant interest to be measured during the simulation's execution. In the studied model variables are used exclusively for counting the number of entities in a given location at a given time. Figure 5 shows an image with the model running a scenario.

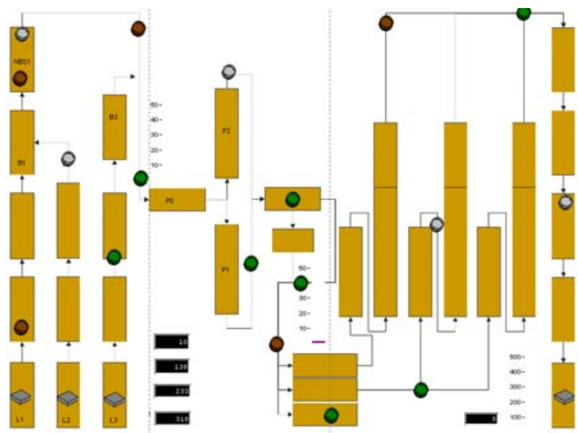

Figure 5. Model running a scenario.

6. Conclusions

Using the gathered information and following general recommendations in considering which location to simulate, the Body Shop was modeled as a processing entities group. The Paint Shop is the most important location to be modeled. Common P2 receives entities and here we can study different priority rules. Once the rules are implemented, each entity continues its process towards Wax and Trim & Chassis Shop.

To model the priority rules, the next factors were used:

- Manufacturing Lead Time was used to measure the total running time.
- Setup Color Change Time was used as remaining operation criterion.
- All operations outside the Paint Shop are the same.
- All demand must be manufactured in the same shift.

Based on the above restriction, the eight rules can be summarized in table 2:

Rule	DESCRIPTION
1. FCFS	*First-come, first-served.*
2. SOT	*Shortest operating time.*
7. LCFS	*Last-come, first-served.*
8. RANDOM	*Randm order or Whim.*

Table 2. Summarized Priority Rules.

Running a scenario for each of the 4 priority rules, we obtained the following table:

RULE	MANUFACTURING LEAD TIME
1. FCFS	7h 45 m
2. SOT	7h 13 m
7. LCFS	8h 07 m
8. RANDOM	8h 23 m

Table 3. Manufacturing Lead Time.

There we can see that the shortest operation time rule gives the best result when compared to other rules in this case.

Future Work

Currently this work is on the process of being improved by adding probability distributions and assignation rules to provide a better resemblance and description of the original system.

Acknowledgments: To the PAPIIT project IN100608, DGAPA; UNAM.

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