



Simulation of a Machining Sequence Using Delmia/Quest Software

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ABSTRACT

This paper describes a case study of analysis and optimization of the mechanical parts machining sequence in a manufacturing cell using a systematic search method and a Quest computer simulation model with graphical representation of the manufacturing processes. Data collected from a company in the aerospace industry was analyzed, organized, and input into a Quest simulation model. The simulation model objective was to determine bottleneck locations and what the optimal batch size should be. The Quest software proved to be a powerful tool in assessing what changes should be made to a manufacturing cell before incurring manufacturing improvements and/or performing actual capital investments. Quest's analytic and visual capacity proved to be a good tool to integrate CAD and CAM, numerical output, graphical part description, simulation of machining sequence, and bottleneck identification.

Keywords: CAD, CAM, Delmia/Quest, optimization, bottleneck identification.

DOI: 10.3722/cadaps.2008.401-411

1. INTRODUCTION

Integration of Computer-Aided Design and Computer-Aided Manufacturing is a key method of improving quality of products and optimizing the time of production. This approach greatly influences both industry and engineering education [4]. The goal of this project was to introduce into a university program and to aircraft companies a practical application of manufacturing optimization for the shortest time of production. In such an optimization model the decision variables are the choice of route of the work-pieces through the machines of the manufacturing cell and the choice of machines [3]. The chosen tool to implement the model was Delmia/Quest modeling software. The project was strongly connected with the Connecticut Center for Advanced Technology (CCAT) and (NALI) National Aerospace Leadership Initiative [5], programs developed to help the aircraft industry in Connecticut and to verify the ability of Quest modeling software for academia teaching as well as to strengthen technology-led economic competitiveness of aircraft companies [1]. CCAT's modeling and simulation initiative is performed closely with companies to help them reduce manufacturing costs. CCAT also works closely with universities, to familiarize the students with Quest, collect the data and help students gain experience in preparation to entering the workforce.

Delmia/Quest Version D5R17SP3 [2] was the software used to prepare, setup, and perform the simulation for this project. Quest provides a single collaborative environment for industrial and manufacturing engineers, and management personnel to develop and provide the best manufacturing flow practices throughout the production design process. With Quest, one can create virtual factories described in 2-D or 3-D formats. Quest contains pre-defined machine, part, and labor elements that allow users to build a simulation model effectively. Fig. 1 illustrates Quest's interface. Within Quest models, users can also design facility layout, process flow, staff schedules, machines arrangement, and incorporate ergonomics constraints. Simulation data can then be manipulated into various charts

and tables. These data can also be extracted from the model and exported into various analysis tools such as Microsoft Excel©.

Quest incorporates real production variables within a plant layout, such as time length between particular machining processes, and laborers' moving and operating speeds. These variables help users analyze the effects on material handling equipment and labor.

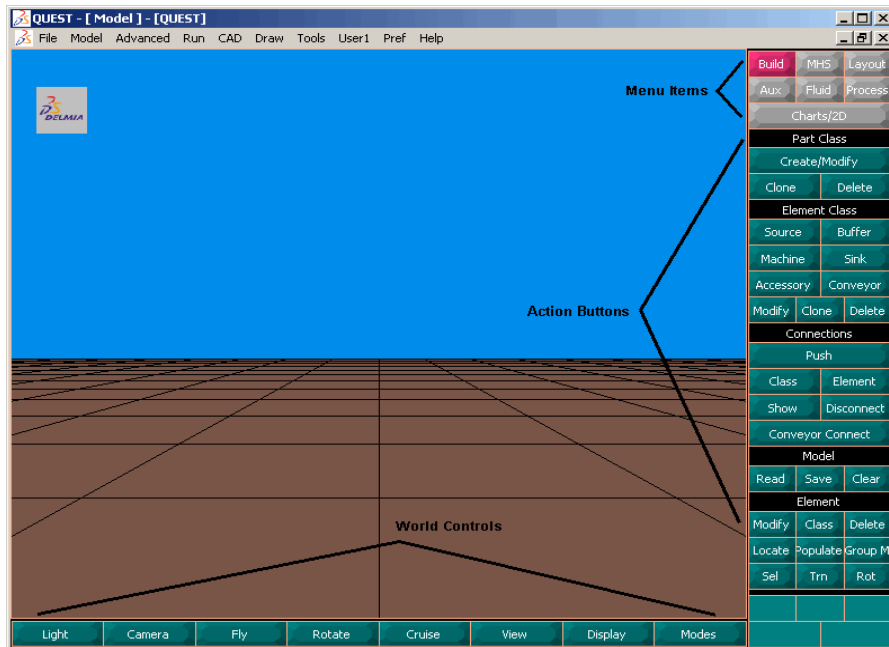


Fig. 1: Quest's interface [2].

Simulation Control Language (SCL) or Batch Control language (BCL) can be incorporated into the simulation model for more complex production processes. An extensive guide on writing these languages can be found in the help files that come with the Quest software.

With the proper implementation of Quest, users can visualize and prevent potential problems and improve existing processes. Quest is also a powerful tool to design, analyze and visually represent complex manufacturing processes and data, for those who are not familiar with the manufacturing process.

2. THE FACTORY TEST-CASE DESCRIPTION

2.1 General Floor Layout

The Quest model analyzed was based on a sample manufacturing facility from the aerospace industry. This manufacturing facility has eighteen different machines and stations, and produces nine different parts in their manufacturing plant. The machines at the factory follow a process layout in which machines are grouped by their functions.

2.2 Machines

There are a total of eighteen machines and stations involved in this project. These machines can be separated into four different groups.

Lathes (shown in yellow in Fig. 2) are machine tools that spin a block of material to perform various operations such as cutting, sanding, knurling, drilling, or deformation with tools applied to the work piece to create an object which has symmetry about an axis of rotation [8]. There are three groups of lathes, two 42" vertical lathes, three 32" horizontal lathes, and three 18" horizontal lathes, for a total of eight lathes in this cell to perform various turning operations.

Mills (shown in green in Fig. 2) are machine tools used for the complex shaping of metal and other solid materials. Their basic form is that of a rotating cutter or end mill which rotates about the spindle axis, and a movable table to

which the work piece is affixed. The cutting tool generally remains stationary (except for its rotation) while the work piece moves to accomplish the cutting action. Milling machines may be operated manually or under computer numerical control [9]. There are two groups of two milling machines in this factory. One group consists of four-axis milling machines and the other group is composed of milling machines that can perform horizontal and vertical turning operations.

Broaches (shown in blue in Fig. 2) use a series of progressively taller chisel points mounted on a single piece of steel typically used to enlarge a circular hole into a larger noncircular shape such as a square or other desired shape [6]. There are two broaches in this factory cell.

A de-bur (shown in orange in Fig. 2) is used for removing the burrs and jagged edges caused by cutting operations. This is often done immediately after the broaching operations. There is one de-burring machine and two inspection stations (shown in gray in Fig. 2) in this facility. One inspection station is located next to the two broaches, and it is used immediately after the broaching operation. The other inspection station is the coordinate measurement machine, or CMM. It is used to inspect parts that have gone through the turning operations (not shown).

In addition, there is a certificate checking station, which is indicated in pink in Fig. 2.

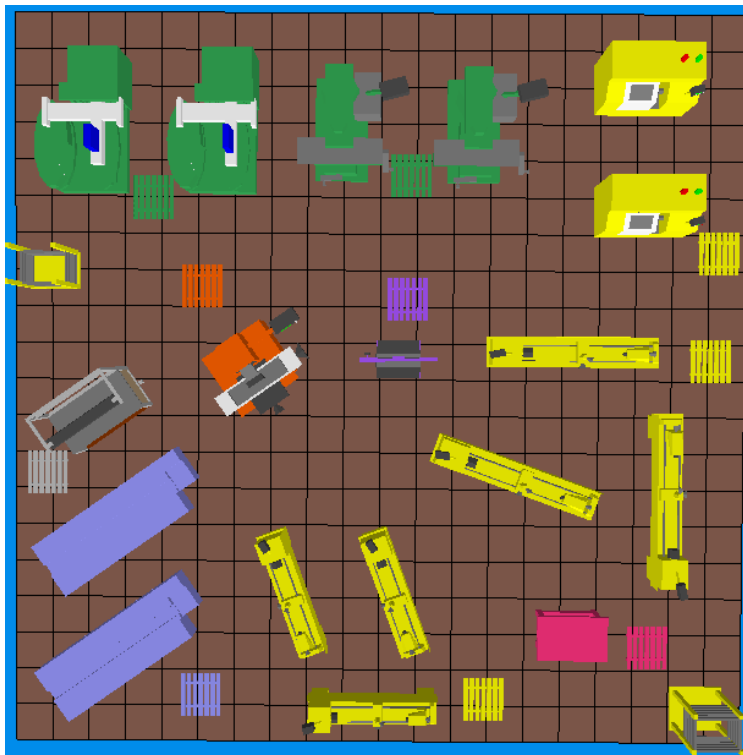


Fig. 2: Top view of layout of the manufacturing facility for this project.

2.3 Parts

There are nine different parts made in this facility. These parts are labeled Part 1 through Part 9 for simplicity. Each part needs to go through a specific set of machines. Different parts require different setups at each machine. As a result, these parts are often being processed in batches. Thus, the optimal batch size is an important factor in optimizing the production process as a whole.

3. SIMULATION

3.1 General Description

The simulation was done using Quest Version D5R17SP3. To prepare for the simulation, the team members carefully examined the data and information collected from the site. All data and simulation related information was

summarized in Microsoft Excel© format. Possible machining sequences were estimated based on the layout of the facility.

3.2 Processes

After careful examination of all processes it was noticed that Part 1, Part 2, Part 3, Part 6, Part 7, and Part 8 have the exact same sequence of process, and very similar process and setup times. It was decided to combine these six parts into one. The process and setup times in this “six in one” part is the weighted average of the process and setup time for the original six parts.

To aid in the identification of parts during the simulation, different parts were represented with different geometric shapes. Part 6-in-1 is represented as a disk, Part 4 as a cube, Part 5 as a stud, and Part 9 as a sphere (Fig. 3).

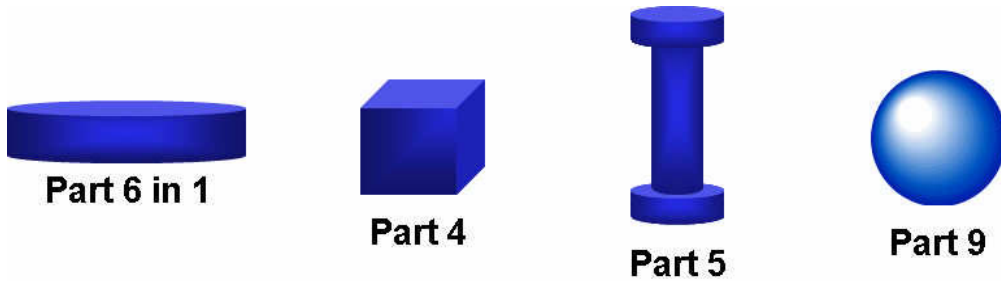


Fig. 3: Simplified representation of different geometric shapes of parts.

When a part visits a group of machines that it has already visited, a new virtual part needs to be created to replace the existing part. This is due to routing restrictions in Quest. After input and output relationships are established among the elements, Quest requires that the user designates where the part would exit the machine or buffer.

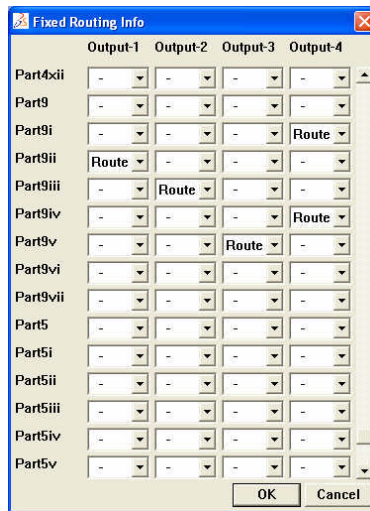


Fig. 4: Routing setup for Part 9 in Quest.

For example, the first three processes of Part 9 are: 18” lathe, 18” lathe, and Certificate Checking Station The 18” lathe group has four outputs:

- Output 1: Certificate Checking Station
- Output 2: Broaching Buffer
- Output 3: Quick Change Jaws
- Output 4: 18” Lathe

To simulate Part 9 going through these three processes, the following sequence was implemented: Part 9 enters the 18" lathe group as Part 9. Part 9 is destroyed and a new part, Part 9i is created and exits via output4 to reenter the 18" lathe group. Next, Part9i enters the 18" lathe group and is destroyed and Part9ii is created and exit via output1 to go to the Certificate Checking Station. The setup followed in Quest is shown in Fig. 4.

Whenever a new part needs to be created in the simulation, a Roman numeral is added to the end of the part's name. To help debug and visualize the simulation, all parts are color coded accordance to the Roman numeral assigned (Fig.5). This helps during analysis when we have to summarize the data.



Fig. 5: Color-coded system used in simulation.

3.3 Queuing System

The queuing system implemented was consisting of an arrival process, a production process, and a queue [3]. The arrival process is such that whenever the buffer of the group of machines of the very first process is free, a new part will enter. In this simulation, the buffers monitored for arrival correspond to the buffers for the 32" Lathe group, 42" Vertical Lathe group, and the 18" Lathe group. Queuing discipline used in this simulation is first-in first-out (FIFO).

3.4 Pooling System

The simulation utilized a pooling system where a part waiting in queue at the buffer would go to the first available machine in the machine group. Such a system is more flexible and reduces process time.

3.5 Part Entry

Parts enter the system from three sources. The sources will monitor the buffers that are the first in the production sequence of each part. Whenever the source detects zero queue (empty) at the buffer, the sources releases a part. This is done to make the model realistic and as close to the actual process as possible. Also some simulation control language for the part entry process was added. This allows the simulation part entry process to resemble closely the actual process at the company.

3.6 Running the Simulation

The simulation was run for batch sizes ranging from 1 to 10. Several additional runs were done to determine total distance traveled by laborers, and the possible impact on the model when an additional de-bur machine and milling machine were added. The results of these runs are discussed below.

4. RESULTS

4.1 General Form of the Simulation Report

After running each simulation, a report on all the data pertaining to the run can be obtained using Quest's single run output. The report is broken down by element class (machines, buffer, labor, etc.), then by individual element (machines_1, buffer_1, labor_1, etc.). Using the report, the utilization, bottleneck, and the optimal batch size was calculated. Once the bottleneck was identified, we tested a few additional models to check how a new layout and additional machines would impact the bottleneck.

4.2 Utilization

Utilization is the ratio of actual output to the potential output. Of all the machines in this simulation it was found that the de-bur machine has the highest utilization rate (Fig. 6). The two rotab mills were the machines with the second highest utilization rate.

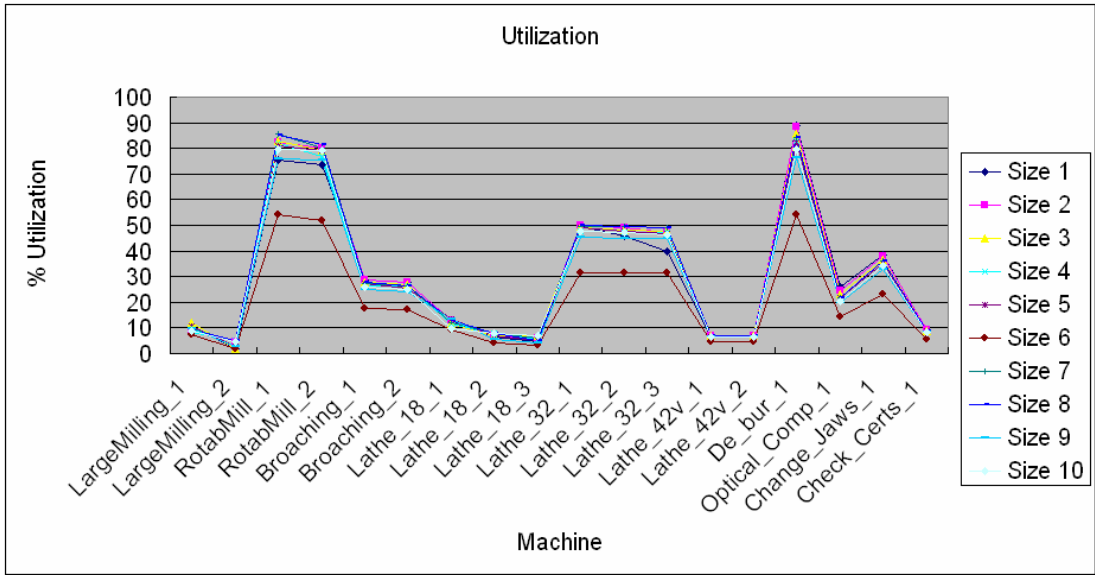


Fig. 6: Graph of utilization rate at each machine.

4.3 Bottleneck

Due to the setup of our model, as mentioned in the Simulation section, all of the queues occur at the buffers, so that bottlenecks will be located at the buffers. Fig. 7 is the average waiting time per part at each buffer. Examining this figure, one can see that a bottleneck is located at the rotab mill buffer, and a second bottleneck is at the de-bur buffer.

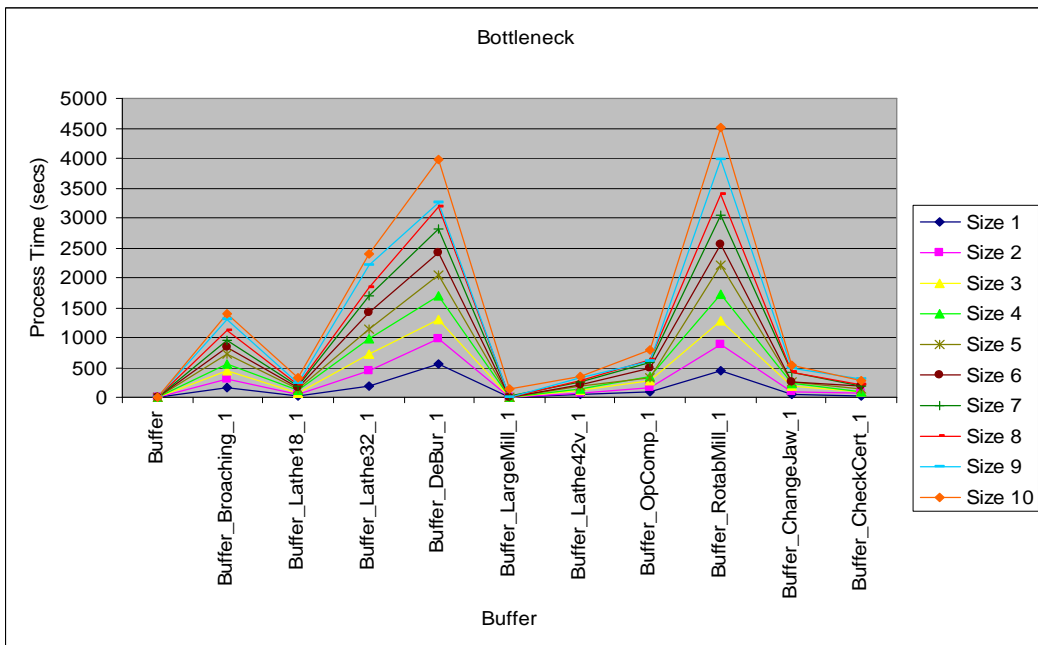


Fig. 7: Average waiting time at each buffer.

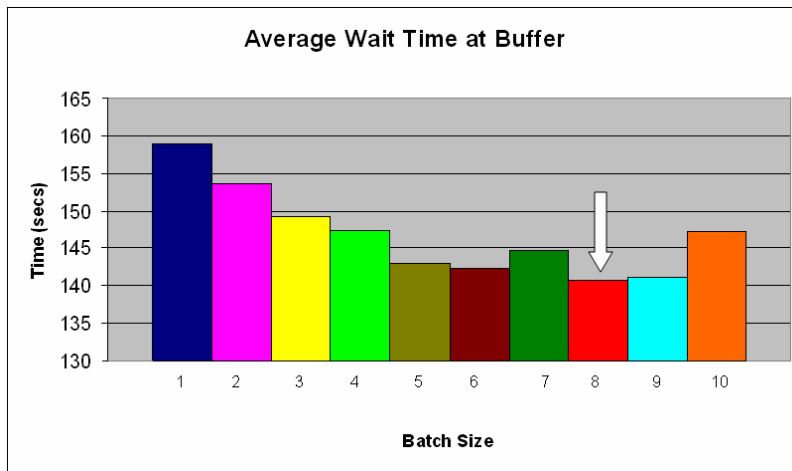


Fig. 8: Average waiting time of different batch sizes at the buffer.

4.4 Optimal Batch Size

Batch sizes from 1 to 10 were tested using this simulation model. When determining the optimal batch sizes, two measures were taken under consideration. The first one is the average wait time per part per buffer. This is done by finding the average wait time at each buffer and divided by the batch size. Fig. 8 shows the outcome. One can see that according to this figure, batch size of 8 is optimal.

Another measure is the average time that each part took at the machines. The outcome of the calculation is shown in Fig. 9. This measure suggests that the optimal batch size is 10. Although the two methods yield two different results, it was determined that using the batch size of 10 the most overall time could be saved.

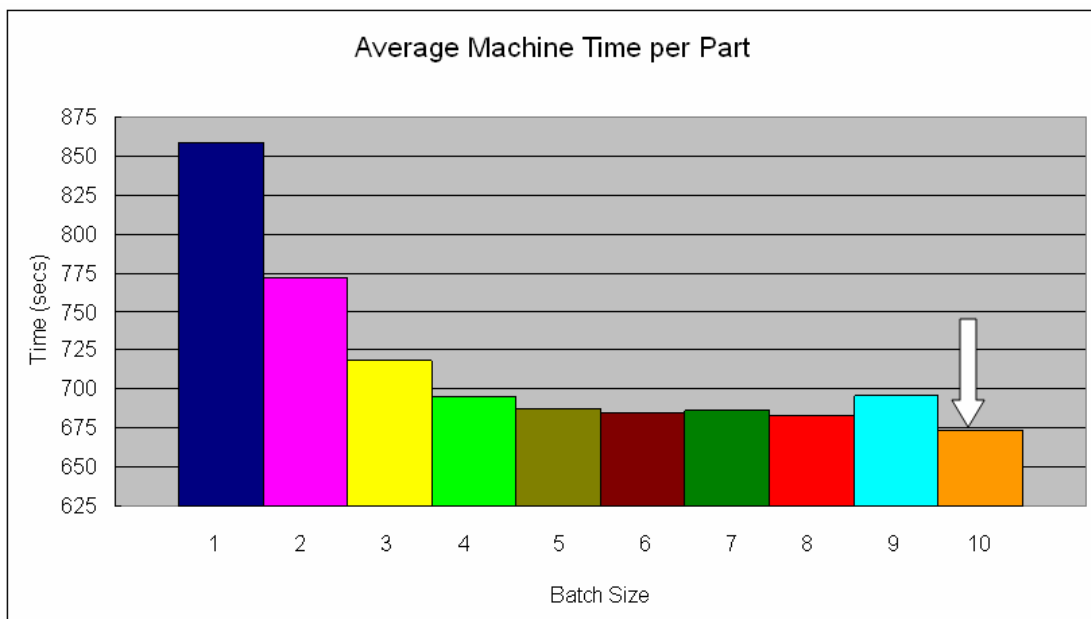


Fig. 9: Average machine time per part.

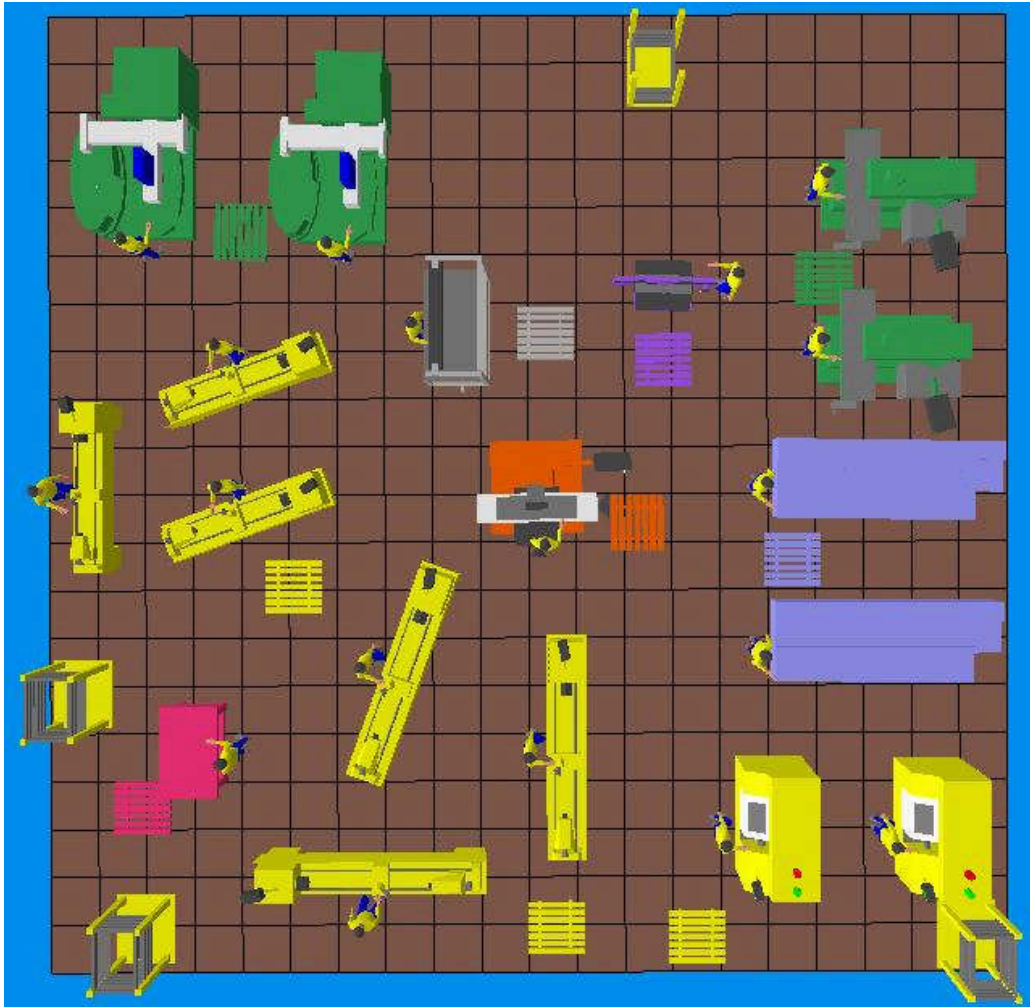


Fig. 10: Purposed new layout.

4.5 New Layout

One of the most distinguishing features of Quest is the ability to calculate distances traveled by the virtual workers. To make use of this useful feature, it was decided to change the arrangement of the plant. After checking trails, it was found that the new layout (Fig. 10), if implemented, can save about 4.33% of total distance traveled by all the workers.

4.6 Additional Machines

Another important feature of Quest is the ability to add new elements to the model very easily. It was determined that the bottleneck was at the rotab mill, and the second bottleneck is at the de-bur machine. An additional run with an extra rotab mill and de-bur machine was performed. By adding a single de-bur machine, the queuing time at the de-bur buffer dropped by 93% (Fig. 11). If both de-burr machine and a third rotab mill were added, the queuing time at the de-burr buffer would slightly increase but the time at the rotab mill buffer be reduced by 32% (Fig. 11).

5. PROBLEMS WITH QUEST

Quest has proven to be a very helpful tool in the design and organization of manufacturing facilities. Though it is a very powerful tool, there are some drawbacks in the program. As the model was built several problems were encountered. These problems can be grouped into two categories: interface design and functional.

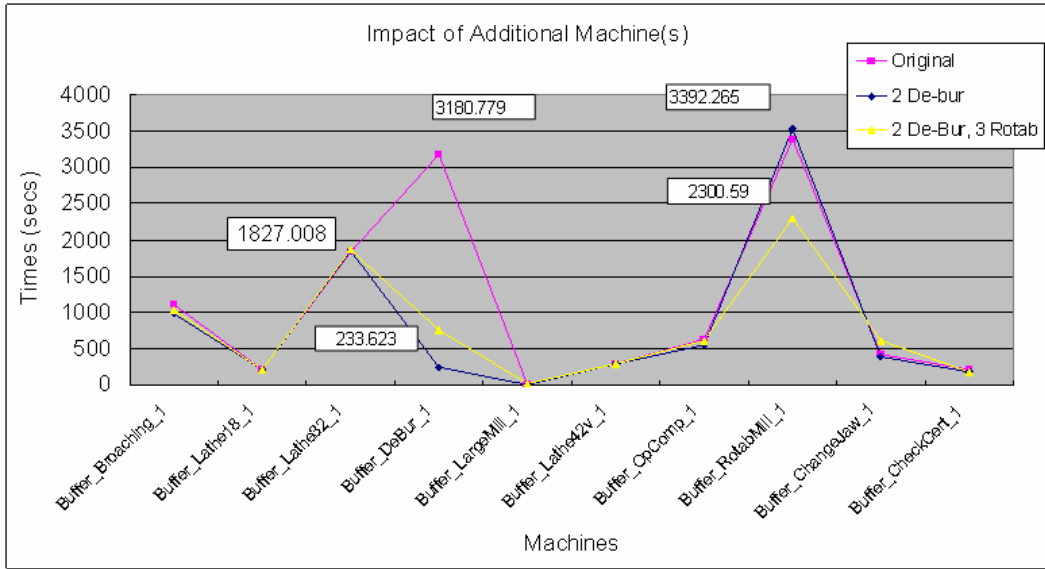


Fig. 11: The effect of adding additional machines.

5.1 Interface Design Problems

5.1.1 User Interface

The first problem is with the user interface. Quest has a unique user interface (Fig. 1) where all of the menu items and action buttons are located on the right. The navigational controls are located at the bottom and are called “World Controls” in Quest. This interface is very different from the Microsoft Windows or Apple OX interface and it is quite difficult to grasp at the beginning. For students, it was difficult to learn and required numerous explanations. It was even more difficult to understand how to use the world controls. This required extensive help of instructors. Reading the user manuals was helpful but not sufficient to operate the controls.

After figuring out how to navigate the confusing interface, another problem the students faced was the complexity of the buttons layout. Once you click on a button in the user interface, a very generic ‘Visual Basic’ type layout with many buttons in which one can alter the input variables will appear (Fig. 12). As one is creating hundreds of parts and subparts it is extremely easy to miss or overlook one of the countless input variables. The overlooking of a single variable can result in problems ranging from simulation failure to inaccurate results which can be very frustrating.

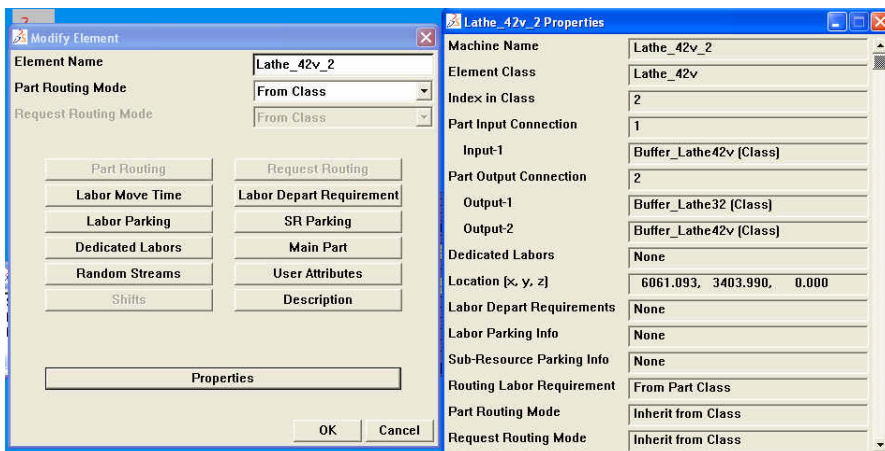


Fig. 12: Layout of one of Quest’s variable buttons [2].

5.1.2 Program Exiting Problem

Another design problem encountered when using Quest happened when one exits the program. When a user exits Quest, it would prompt the user to confirm the exit. Unlike most commercial programs, however, it will not give the user the option of saving before exiting. There were many instances where part of work was lost as a result of exiting the program.

5.2 Functional Problems

5.2.1 Revisiting the Part

The first functional problem encountered occurs when a part needs to re-visit a machine that it has already visited. The program will simply not run and produce a simulation failure. A solution to this problem is to create a new identical part before the entry to the every one of the machines. Doing so might affect the numerical outputs of the simulation. After several discussions it was decided that the new part was to be named with the same name as the old part except that an additional character was added at the end of the new part, so that appropriate adjustment to the data could be made. For example, part one would be created into Part1i, Part1ii, Part1iii, and so on up to the number of machines that part visited (Fig. 4). This meant that each machine created a new sub-part which represented how far the part as a whole had made it through the manufacturing process. These parts were also color coded so that one could tell how far it was through the process just by looking at the color. In order to make this work, buffers had to be created before each group of machines. This made creating parts extremely tedious and time consuming. Creating a single part took many hours of inputting variables for each subpart. The only benefit was that when problems arose, the color coding made it a little easier to troubleshoot which step in the process was failing. This project only had five parts and only ten machine groups to input into the program. The slight benefit of easier diagnostics did not outweigh the fact that it took many hours to input all the variables for all the subparts. Therefore, scalability of the model is a concern when using Quest.

5.2.2 Problems with Laborers

Another problem encountered was related to modeling the movement of the laborers. Quest's virtual laborers often stand around at the prescribed labor point waiting for part, rather than going to machines that need a laborer. One possible solution would be to create numerous labor points at each machine. Another solution would be to increase the number of laborers. Both approaches do not seem to be working well. Probably the best solution is to simulate with laborers only when a strong visual representation is needed. All the data was obtained by running simulations without the laborers. Although difficulties and problems when creating the simulation model in Quest were encountered, the magnitude of this software's capability far outweighs any and all negative drawbacks.

6. BENEFITS OF USING QUEST

The application of the Quest software could be very beneficial in teaching and manufacturing practice. Though this software is primarily prepared for manufacturing optimization, it has both design and manufacturing possibilities. If more features, such as CAD software for part design, were integrated directly into the program, the Quest software would become even more powerful. Once the design and manufacturing can all be controlled under one program, Quest would be the ultimate engineering tool. In the United States alone, manufacturing is a multi-trillion dollar industry [7]. Through the integration of Quest, companies would be more efficient and manufacturing more "lean". The partnership between the University of Connecticut and CCAT is one small step towards making Quest an essential component of the U.S. manufacturing industry.

7. RECOMMENDATIONS MADE TO THE COMPANY

7.1 Batch Sizes

Based on the Quest model and outputs, it was recommended to the company that all the parts should be made in batch sizes of ten. The company currently manufactures their parts in batch sizes of five. Although batch sizes of eight produce the lowest waiting time in the buffers, batch sizes of ten produce the lowest amount of machine time per batch. Though both sizes would save time, the total time saved when using batches of ten would be greater than the time savings when the batch size is eight.

7.2 Additional Machines

The second recommendation is to add an additional de-bur machine. Adding a second de-bur machine would reduce the average wait time at the de-burr buffer by 93%. (Fig. 11) This would greatly reduce the process time for the entire production plant. If this de-bur machine is purchased, it is suggested to place it next to the existing de-bur machine to

make training and maintenance activities easier. This will also ensure that the distance workers have to travel will not be greatly affected by the addition of this new machine.

7.3 The New Layout

If changing the location of the machines is possible, the final recommendation is to implement a new layout. The machines could be large and heavy. There might be some electrical and other constraints on the machines placements but if these are not an issue, adopting a new layout would make the laborers' work easier and help to overcome potential accidents or injuries in the plant.

8. CONCLUSIONS

Before Quest was introduced, the students would normally write their own programs using general computer languages such as C++ or Visual Basic or some other special simulation software on a case to case basis. In engineering teaching Quest can be also a very useful tool for designing and studying Computer-Aided Design of manufacturing processes. It allows verification of the floor design, the manufacturing cell configuration and the process of machining and production performed in the cell designed. Ability to illustrate and simulate functioning of the manufacturing cell has tremendous educational meaning and allows the student to learn about their design imperfections and correct them. Quest's industrial application can greatly reduce manufacturing costs, enhance production rates and efficiency, as well as would help in the planning and explanation of manufacturing layouts to a wider range of users. It has analytical and visual capacity. The analytical output can be a base for detail analysis but the animation model would allow visually illustrating and examining the manufacturing process. Using Quest could result in improvements of the factory floor organization and workers safety. Eventually it would be a benefit for domestic industries and help manufacturing enterprises to stay competitive with overseas companies.

9. ACKNOWLEDGEMENTS

This project started as a joined initiative of the University of Connecticut (UConn) and Connecticut Center for Advanced Technology (CCAT). It was done within the scope of a CCAT grant. The basic Quest runs were done by Mu Li and Sean Powers. The authors wish to thank CCAT personnel, especially Mr. Tom Scotton and Mr. Jonathan Fournier for their constant support in this project. We also like to thank UConn students Mr. John Kirejczyk and Mr. Eric Fleckenstein and the Aircraft Company engineers and staff for their involvement in the data collection process; Mr. Salvatore Ginella of TechniGraphics Corp. and Delmia/Quest Company for generously attaining licenses for the Quest software; and Prof. Ed Crow without whose help the project would not have started.

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