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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Automated Process Application in Steel Fabrication and Subassembly Facilities; Phase II (Process Comparison)

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
National Steel and Shipbuilding Company
San Diego, California

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AUTOMATED PROCESS APPLICATION IN STEEL FABRICATION AND SUBASSEMBLY FACILITIES PHASE II (PROCESS COMPARISON)

A PROJECT OF

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

FOR

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

SHIP PRODUCTION COMMITTEE

SP-1 FACILITIES AND ENVIRONMENTAL EFFECTS PANEL

BY
NATIONAL STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CA

MAY 1999

Final Report

NSRP 1-96-6

Automated Process Application in Steel Fabrication and Subassembly Facilities
Phase II
(Process Comparison)

Contract Number N00167-94-H-0038

A Project of

The National Shipbuilding Research Program

For

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Ship Production Committee

Sp-1 Facilities and Environmental Effects Panel

By

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San Diego, CA

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May 1999

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EXECUTIVE SUMMARY

In an effort to produce cost competitive ships in a time of reduced Defense spending and dominance of the world commercial market by foreign yards, the American shipbuilding industry is investigating methods that will streamline production and reduce fabrication and assembly times. One such method is the introduction of automation into steel fabrication and subassembly processes. Many of the processes in these areas are both labor intensive and repetitive, characteristics that are ideally suited to be handled by automation. The drawback, however, is the capital cost associated with automation, especially when it is not known whether the automation will produce a positive return on the investment dollar. Computer simulation is being used in other manufacturing industries, worldwide, to gain insight into how the introduction of new resources affects the company's current manufacturing capabilities and whether or not the new resources will produce a positive return on investment. The objective of this project is to utilize computer simulation to provide American shipyards with a method of determining which of their specific processes, in steel fabrication and subassembly, are likely candidates for automation and to what degree.

The project is divided into two phases. In Phase I, the modeled yard, National Steel and Shipbuilding Company (NASSCO), was used to define and understand existing 'As-Is' steel subassembly and fabrication processes. Once defined, a computer simulation software package was selected to model the processes. The models were then used to identify opportunities, such as bottlenecks and constraints, in the system that could be potential areas for automation. In Phase II of the project, new, 'To-Be' models were created which included automation. The 'To-Be' and 'As-Is' models were compared in an effort to determine the effect automation has on the performance of the system and Return on Investment (ROI).

This is the Phase II Final Report. It details the approach taken by the NASSCO project team to carry out the Phase II portion of this project; from identifying areas within Steel Fabrication and Subassembly that are suitable for automation to determining the payback period necessary to implement the automation. The report contains information on the process steps that should be followed when determining automation possibilities in fabrication and subassembly processes, the project team's view of building the simulation models, and the approach taken to analyze those models. The Phase I Interim Report outlines setting up a simulation project; from creating a simulation specification and choosing computer simulation software to running experiments that will determine the bottlenecks in the system. Decision points and the logic applied by the project team at those points is included throughout both reports to help the reader to gain insight into why or why not the same reasoning may be applicable to his or her yard.

Two models, the Profile Fabrication Area and the Panel Line, are used in this report to take the reader through the analysis of a simulation model from identifying bottlenecks and constraints to evaluating automation options for the system. From this analysis, it has been determined that a major benefit in using automation in the Profile Fabrication area or Panel Line comes from the labor savings involved in employing robotic cutting, fitting, and welding systems rather than increased throughput. These systems are capable of producing the same throughput as the existing processes with 12% and 67% of the manpower, respectively.

Computer simulation has proven to be a valuable tool in this project. It not only allowed the team to forecast the effect of future changes to the system's performance, but also provided a means to focus attention on the strengths and weaknesses of the current process. The key to success in both cases was proper planning of the project including the development of clear objectives. Without taking these measures, the project would have easily become sidetracked due to excessive model detail and unclear goals. Such experiences tend to foster undue negative feelings toward new tools such as computer simulation. Properly prepared for, however, computer simulation can achieve the same success in the American shipbuilding industry as it has seen in other industries such as automotive, defense, medical, and electronics manufacturing.

1.0 INTRODUCTION

The principal objective of this National Shipbuilding Research Program (NSRP) project was to develop a methodology that identified specific shipbuilding processes within steel fabrication and subassembly that were good candidates for automation. In addition, the degree and mix of automation that would have the best overall effect on the defined areas was to be determined. The core of the methodology was a "what if" type analysis using computer simulation models. By using the simulation model(s), one can select an optimum mix of automation within steel fabrication and subassembly operations that will meet selected production goals.

This project was divided into two phases - analysis of current 'As-Is' processes (Phase I) and comparison to 'To-Be' models incorporating automation (Phase II). This report is the Phase II Final Report of this NSRP project, which was conducted by the Industrial Engineering department at National Steel and Shipbuilding Company (NASSCO) in San Diego, California. Portions of the project were performed on a contractual basis by First Marine International and by Kiran & Associates. Project participants have backgrounds in ship production, production automation, and computer simulation.

<u>Background</u>

To become more competitive in the world commercial market, the American shipbuilding industry must streamline current production methods to reduce span times and production costs. One method of accomplishing this is to automate production processes. Automation lends itself to labor-intensive, repetitive processes. Steel fabrication and subassembly, the initial stages of ship production, consist of many production processes that are both labor-intensive and repetitive. These two areas have great potential for the application of process automation and are therefore the focal point of this project.

The automation of shipbuilding production processes is very capital intensive, and the interdependencies between these processes are such that extensive analysis and justification are required by management to make prudent decisions related to the application of automation. Computer simulation software is a tool that can be very beneficial in this analysis and justification. Using simulation models, various automation scenarios can be evaluated for their impact to a particular process, as well as, to the overall production system. This can be done within a relatively short period of time and without the need to make capital expenditures. The data output from simulation models can help management to optimize their capital expenditures for process automation. For this reason, computer simulation has been selected as the primary decision making tool for this project.

In Phase I of this project, a computer simulation model of a sample shipyard's 'As-Is' production processes for steel fabrication and steel subassembly was created. NASSCO was used as the sample shipyard. Using the 'As-Is' simulation model, system bottlenecks, constraints, resource requirements, and throughput capacities have been defined and documented. The results are detailed in the Phase I Interim Report. The second phase of the project included benchmarking activities to identify 'world class' methods and processes for steel fabrication and steel subassembly. The results of the benchmarking activities were used to define various automation scenarios for the sample shipyard. These scenarios were then simulated using modified versions of the original "As-Is" simulation model. Projected impacts to the production system for the various automation scenarios were defined by the outputs of the simulation models. The ultimate goal of these efforts was to use the simulation results as a direct input to related cost benefits analysis.

2.0 PROCESS STEPS

Figure 1 shows the general steps for investigating automation possibilities in production areas using computer simulation. These steps were applied to the Steel Fabrication and Subassembly Areas for the purposes of this project.

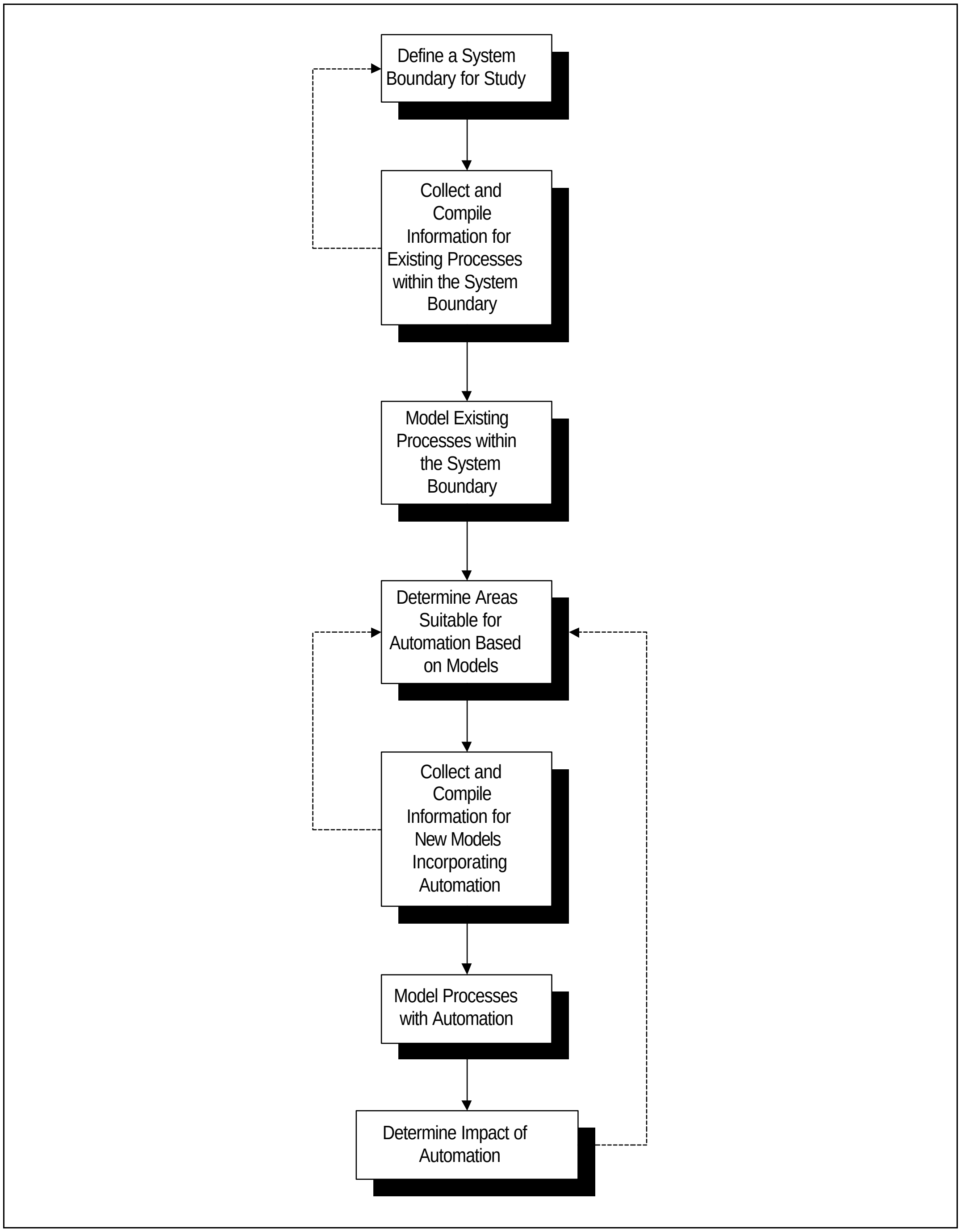


Figure 1: Process Steps for Investigating Automation Possibilities Using Computer Simulation

The steps in the flow are carried through in series, however, at three points shown as dashed lines on the flow diagram, information uncovered may be used in redefining a previous step's objectives. For example, the collection of data for the existing or automated processes may indicate that a certain process need not be included in the system boundary or that a certain type of automation may or may not produce positive results in the particular area for which it was chosen. In the same manner, the results of determining performance, payback, and return on investment may indicate that more combinations of automation, a different mix of automation, or an entirely different type automation is necessary in order to meet the performance improvement objectives desired by management. Each of the steps is explained in greater detail in the following sections.

3.0 DEFINE SYSTEM BOUNDARY

Defining a boundary for the system to be investigated is the first step in the process. Some factors that are important in defining the system boundary include:

- Objective of study
- Level of detail of the models
- Available information
- Project Schedule

The system boundary for this NSRP project is shown in Figure 2. Since the objective of the project was to determine areas within the Steel Fabrication and Subassembly area that are suitable for automation, a large boundary was intentionally created to encompass the entire area. The boundary began at the head of the conveyor that feeds the Blast and Prime Line. All steel, whether plates or shape, that enters the yard goes through the blast and prime process to protect it from the elements. The boundary ends at the point where a product leaves the Fabrication or Subassembly area to be moved directly into Block Assembly or a storage area where it will remain until it is required for block assembly. This system boundary includes all of the processes within the Steel Fabrication and Subassembly area at NASSCO. The geographic locations of the individual areas within the yard can be seen in Figure 3.

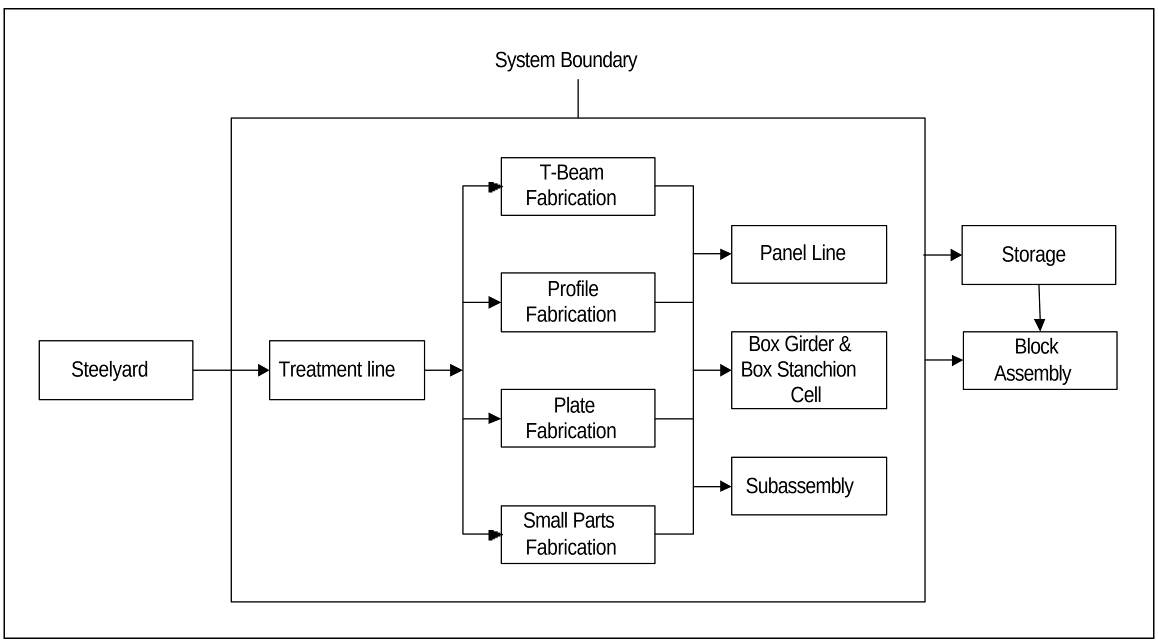


Figure 2: System Boundary for NSRP Project 1-96-6

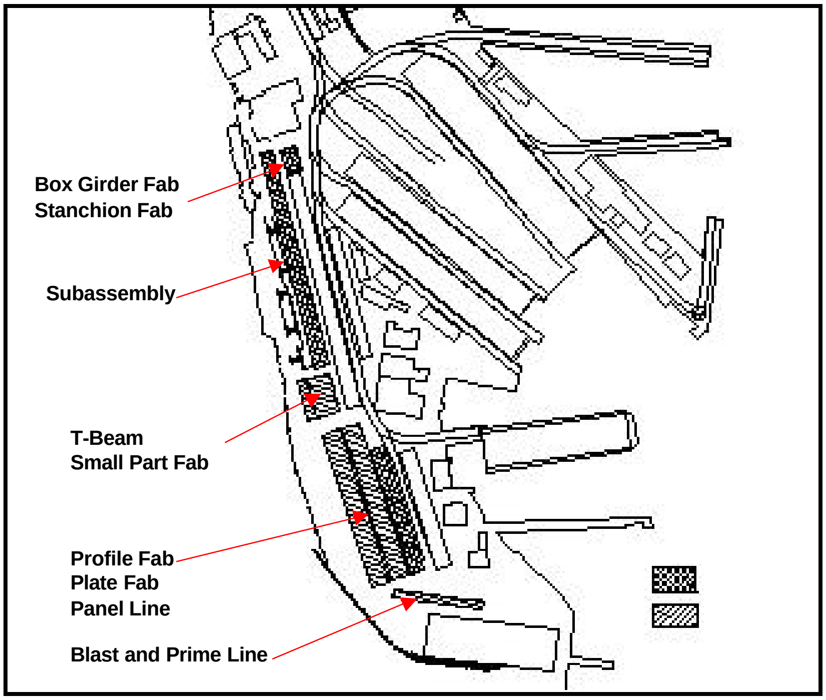


Figure 3: Geographic Locations of Steel Fabrication and Subassembly Locations at NASSCO

Because the project objective required that such a large area be modeled, but the level detail necessary to make decisions was at the process level within the individual process areas, each individual process location within the system boundary was modeled with its own system boundary. The basic characteristics of these individual boundaries include:

- The boundary starts at a pre-staging location, conveyor, or collocator car immediately prior to the first processing location in the modeled area. Modeling this pre-process location made it convenient to control material input in the system by allowing the process to determine the rate at which material is being taken into the system rather than forcing a rate on the system.
- The system boundary ends with the final grouping of the finished product before it leaves for a new process location or a pre-staging area for a new process. For example, finished profile parts are palletized in the model by next assembly (end of system boundary) before they are moved into a storage area prior to being used in Assembly.

Figure 4 shows the relationship between the system boundary for the individual processes and the functions both inside and outside the boundary.

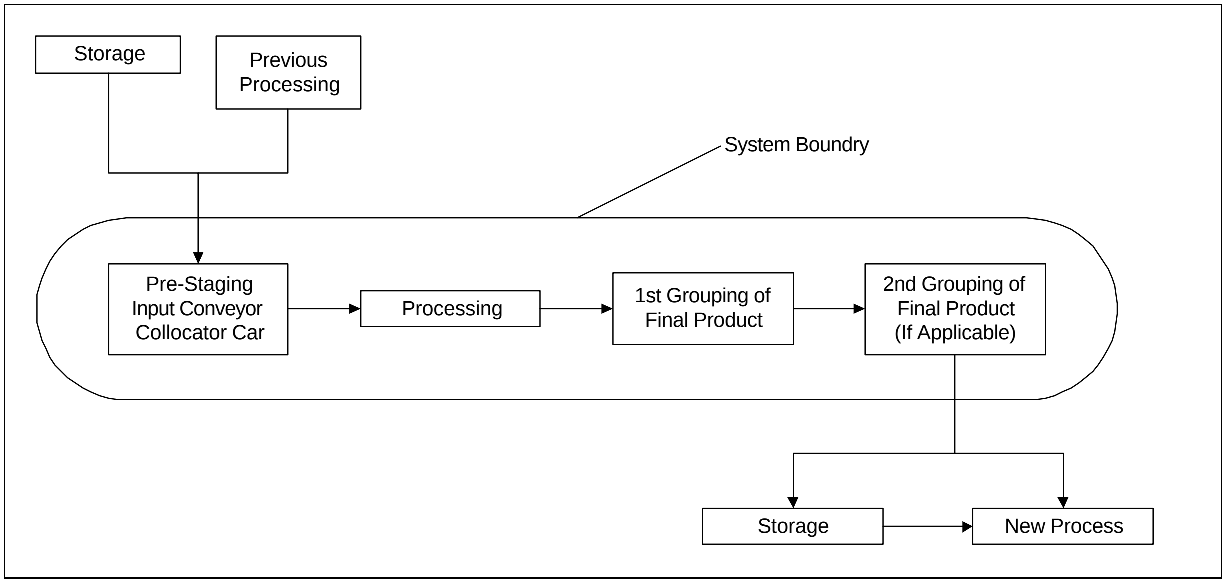


Figure 4: System Boundary for Individual Steel Fabrication and Subassembly Locations

4.0 COLLECT AND COMPILE INFORMATION ON EXISTING SYSTEM

Once the system boundary has been defined, the information for the system needs to be collected. Out of all of the steps in conducting a simulation project, this is the longest duration item. When collecting the information for the system it is important to keep in mind the same factors that influenced the formation of the system boundary:

- Objective of study
- Detail of models
- Available information
- Project schedule

In addition, the number of resources available to collect and compile the data should also be considered. With these factors in mind some of the information collected might include:

- Manpower levels for the area
- Product throughput for the area
- Intermediate products produced
- Process times
- Down times
- Conveyor speeds
- Setup times
- Equipment limitations and capacities
- Equipment speeds

There are three different ways in which this information can be collected and input into the model. The data can be in the form of a constant number which represents an average, a distribution to represent variation, or an actual number occurring in the sequence that it occurs in real life.

Averages work well when variation in the work does not affect the operation of the system. They are easier to program and interpret when analyzing the results of the model runs. In addition, averages are used in most cases to track the performance of the process so they are usually readily available. This will reduce the time necessary to collect the data for the computer models.

Variation in the product or process that may affect characteristics of the system such as process time can be modeled using distributions. This is a quick way of getting statistically accurate results. Distributions work well when analyzing large amounts of data or over long time periods since the model needs a sufficient amount of time or product to accurately represent the distribution. When using the distribution, however, it is more difficult to conceptually understand some results since they will have to be thought of in terms of a continuous distribution rather than a constant number (average). Another factor to keep in mind when using distributions is that it doesn't necessarily represent the effect of a specific order of numbers or events (such as a schedule) since the computer assigns instances of values based on the distribution rather than a user-defined order.

Actual numbers in the sequence they occur can be used in the model to capture the real life order of events. This type of data use is more difficult to program, however, it provides the modeler the ability to test certain sequences of values (such as schedules). The information must often be written in data file that will be read by the computer simulation software. Programming is then done to map the data within the file to certain variables within the model. This process can become quite complex when large amounts of data are involved. Large amounts of input data can also have an effect on the speed at which the model runs. Being able to have better control over the sequence of events, however, is one advantage of using an actual data file over a distribution. Another advantage is that the data file can be used to determine exactly where trouble spots occur in the model because the user has the exact order in which the data was fed to the model line by line.

The information for the averages, distributions, or actuals for the system can come from a number of sources including:

- Time studies
- Schedules
- Historical information on past contracts
- Process analysis reports
- Equipment specifications
- Interviews of process stakeholders and participants

The information for the "As-Is" Profile Fabrication Area came from a Process Analysis Team tasked with defining the material flow in the area. Once the material flow was defined, changes to the processes were proposed in order to reduce touch labor in the area. The Team developed flowcharts with manning and process times for all of the actions carried out in this area. An excerpt from these flowcharts can be seen in Appendix A.

The information for the development of the "As-Is" Panel Line model came from time studies done on the line. Additional information was provided by a process analysis done to investigate the possibilities of improving the line's cycle time to 4 hours/panel. In addition to a reduced cycle time, it was anticipated that the change would make the scheduling of panel removals from the line easier to accomplish. Process times and manning were the result of this analysis. A flowchart from the analysis of the Panel Line is included in Appendix A.

5.0 MODEL EXISTING SYSTEM

Once a sufficient amount of data has been collected to create a general skeleton of the process area being modeled, the computer programming of the model can begin. Modeling the areas is, in most cases, the shortest duration process in the project. Because of the large area that was modeled in this project, the models for each individual area within the system boundary were kept general enough to make the models easy to build but detailed enough to provide useful results. There is a balance between detail and time to build any model, and this should be agreed upon at the onset of the project.

In general, the models for this project were created to be as optimistic as possible. By doing this initially, it was easier to identify problems that were inherent to the operation itself rather than non-process causes such as equipment age, material shortage, scheduling problems, etc. The models could be considered a "best-case" scenario. Downtimes due to equipment breakdown were not modeled, and material arrives at the process location when needed. Therefore, the problems that arose in the system were process inherent rather than being due to equipment or support from outside the system.

5.1 Profile Fabrication Area

The layout of the Profile Fabrication Area is shown in Figure 5.

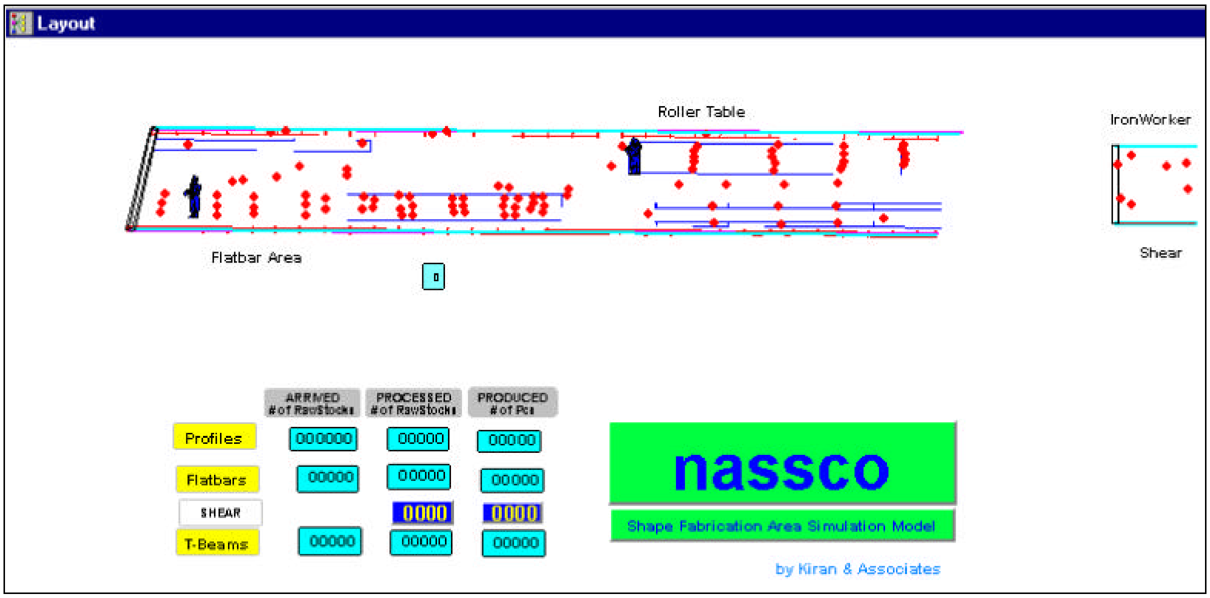


Figure 5: Layout of NASSCO "As-Is" Profile Fabrication Area

Raw stock profiles are brought into the Profile Fabrication Area in carrier blocks. The number of raw stock profiles in each load and the frequency of delivery are based on averages and remain constant during the simulation. The raw stocks are then moved to the appropriate tables by an overhead crane where they are processed accordingly. The number of parts manually cut from each raw stock is determined by using a triangular distribution that specifies the minimum, maximum, and most likely number of pieces cut. This distribution is based on data from the Process Improvement Team and represents the variation in the number of pieces cut from a raw stock. The layout and burning times for each part are constant and are based upon the average manual process time for the operation. Once processed, the finished parts are moved off the table by the overhead crane and transported to either the Shear/Ironworker Area for further processing or palletized by next assembly before exiting the system. Parts that are finished with the processing in the Shear/Ironworker Area are also palletized before exiting the system.

5.2 Panel Line

The layout for the existing Panel Line is shown in Figure 6.

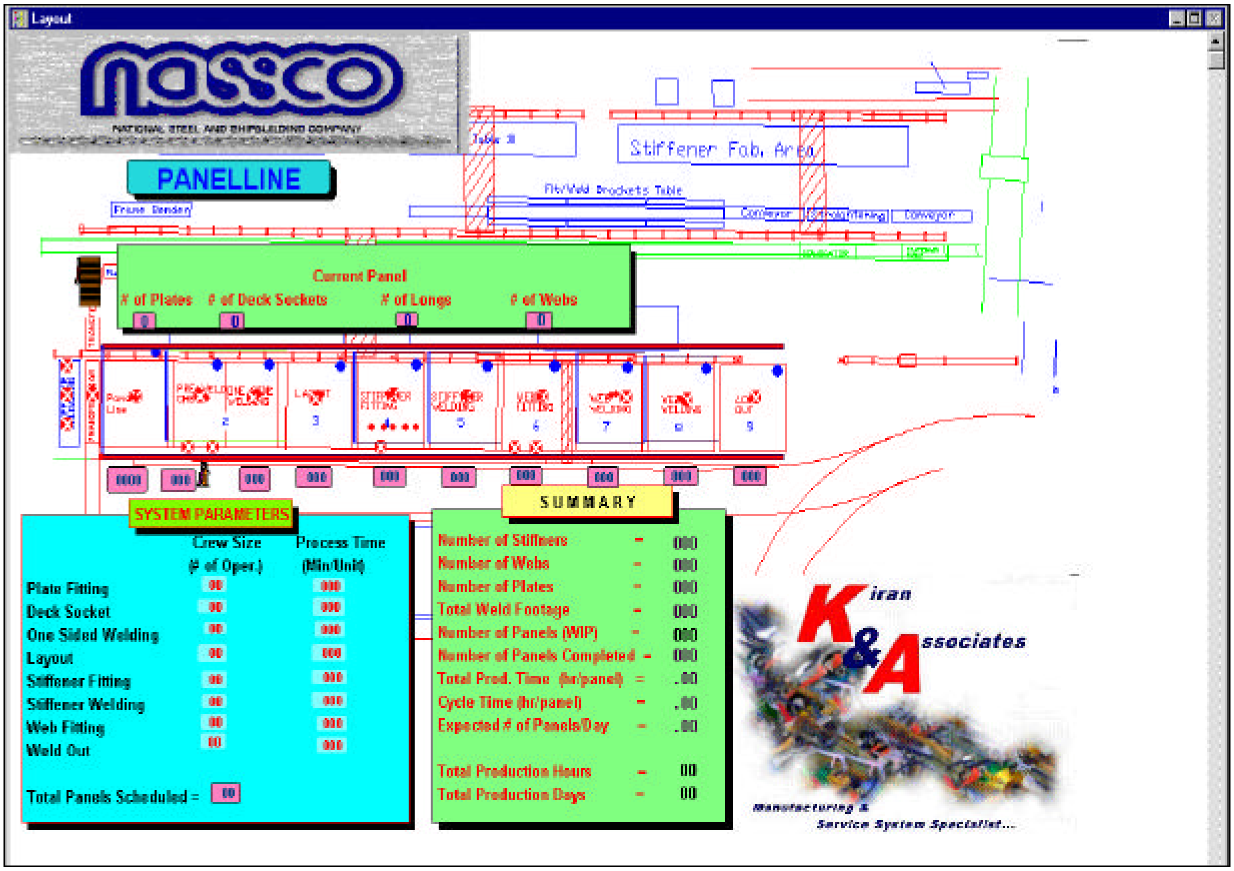


Figure 6: Layout of NASSCO "As-Is" Panel Line

The panels built in the Panel Line model are based on the average work content of the panels built on the existing line. The "average work content panel" was used to simplify the manual analysis tasks of the Process Analysis Team. The panel consists of:

- 5 plates
- 120 deck sockets
- 12 longitudinal stiffeners
- 5 transverse webs

The plates for each panel are fit and tack welded in Station 1. Deck sockets are also fit and welded here. The fitting and welding processes done in Station 1 are manual operations. Once the entire panel is tack welded together it is moved into Station 2. The panel is seamed by an automatic one-sided welder and then moved into Station 3 where layout and perimeter burning is done manually. In Station 4 the longitudinals are manually fit and tack welded to the panel. The longitudinals are welded four at a time in Station 5 by a second automatic welding machine, and the panel is then moved to Station 6 where the transverse webs are fit. Once the webs are fit, they are manually welded out in Stations 7 and 8. Finally, the weld pickup is done, and the panel is inspected in Station 9 where it waits until the next stage of construction is ready to accept it. Both the manning and process times used in the model remain constant during the running of the simulation and are based on averages calculated during normal yard operation.

5.3 Optimization of Models

Depending upon the objectives of the project, it may be beneficial to spend some time determining if the baseline model can be further optimized through simple changes such as material input or manning. Because the objective of NSRP 1-96-6 was to determine which areas were suitable for automation, it was decided that the areas to be used in the comparison should not only be representative of the product throughput and resource usage found in the existing NASSCO areas, but they should also make the best possible usage of those resources. This optimization was done, not by remodeling the area, but by making simple changes such as the number of heads utilized in the process or by adjusting the material input. This step allowed the project team to gain insight into the potential of the existing process (possibly eliminating the need for automation) and ensured that when comparing the existing system to alternative options that the results would reflect the best possible case for both.

The Profile Fabrication Area had opportunities for optimization since the table space of the area allowed for a variance in material and manpower levels. Both were experimented with in order to optimize the area based upon throughput and utilization of the resources. In fact, it was realized through this optimization process that the area could operate at a slightly lower manpower level then currently employed in the existing system with only a slight decrease in overall area output, but a large increase in resource utilization.

A similar process was performed using the Panel Line model. The manning in Stations 7 and 8 was reduced as a result of this process to increase the utilization of the resources in these stations.

6.0 DETERMINE AREAS SUITABLE FOR AUTOMATION

Once the model has been tested to make sure that it is performing properly and optimized if necessary, it can then be run through a series of experiments to determine the areas that might be suitable for automation. Through the data collection and flowcharting of the various processes within the Steel Fabrication and Subassembly Area it was realized that many of the processes which are performed in these areas are already semi-automated and do not necessarily need to be upgraded to a fully automated process. In many cases, a fully automated process for an area does not exist on the scale that is necessary in shipbuilding. Increased automation in the material handling of the product might be feasible, but in many cases, the material handling within the system boundaries was not found to be the bottleneck to the system. Therefore, only four systems within the Steel Fabrication and Subassembly Area at NASSCO were deemed to have a possible improvement in product output through the use of automation. These areas are:

- Profile Fabrication Area
- Panel Line
- Subassembly Area
- Boxgirder Area

Improvements in the other areas could be attained by increasing the machine speed of the key processing resources such as the NC plate burning machine, but the results of doing this could be determined without conducting a computer simulation project. The results of the “As-Is” Profile Fabrication Area and the Panel Line models are shown in the following sections.

6.1 Profile Fabrication Area

The manning for the Profile Fabrication Area is shown in Table 1. The real-life manning level is varied depending upon schedule demand for the product. The level shown in Table 1 is slightly lower to the average manning level utilized in the area today due to the optimization that was performed during the running of the model.

Manning in Model	
Profile Layout	3
Profile Burners	4
FlatBar Layout	4
FlatBar Burners	2
Deburr	1
Bevel	1
Ironworker	1
Shear	1
Total	17

Table 1: Per-Shift Manning of "As-Is" Profile Fabrication Area

Using the manpower in Table 1, the resulting throughput for the area is shown in Table 2.

Arrivals	
Profile Raw Stock	3394
FlatBar Raw Stock	3397
Total	6791

Parts Produced	
Profiles	6225
FlatBar	16342

Table 2: Throughput for 840 Production Hours in "As-Is" Profile Fabrication Area

After running the model and identifying the resultant output, the use of the locations and resources should be investigated. Figure 7 is a portion of a much larger graph from ProModel (the simulation software utilized in this project) that shows the Single Capacity Location States for the positions in the Profile Fabrication Area. These locations are "Single Capacity" because only one product at a time may be processed in the specified location. This graph is a rolled-up percentage of time each area is in operation, setup, idle, waiting for resources such as manning, blocked or down.

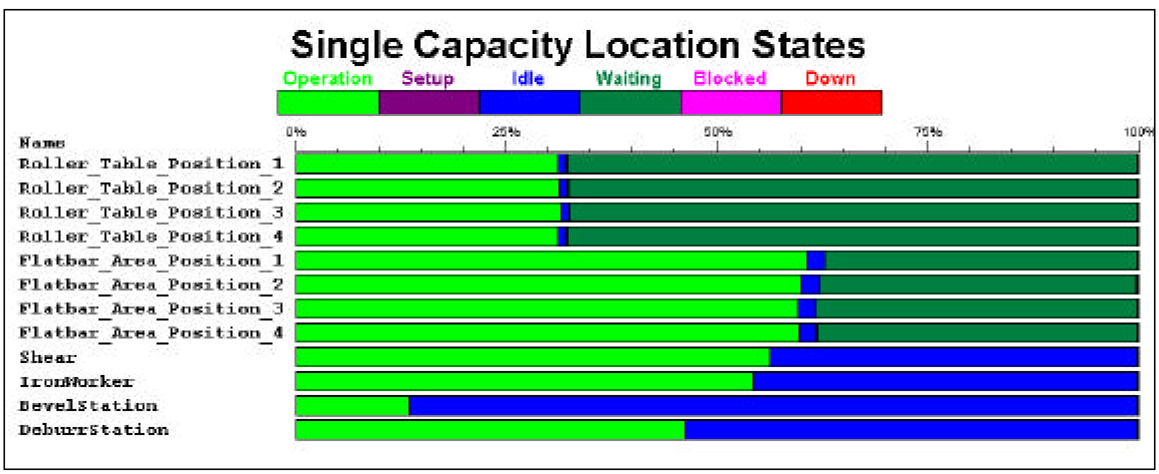


Figure 7: Single Capacity Location States for "As-Is" Profile Fabrication Area

The time spent in operation for these locations is low. The percentages range from approximately 31% in the Roller Table area to 60% in the Flatbar area. Ideally, the locations should be in operation more than 80% of the time. The largest balance of the time in the Roller Table and Flatbar areas is spent waiting for resources. Increasing the number of people performing layout and burning operations in these areas would decrease the wait time, however, the higher concentration of people in the same work area would increase the hazard to the workers of being injured by misdirected sparks during the burning operations. Current NASSCO safety regulations require that there be at least one unoccupied row between the adjacent layout, burning, and crane operations. This results in having a maximum manning level in the Roller Table area of 10 people and no more than 6 workers in the Flatbar area. The wait time, therefore, is inherent to the operation procedures in these areas.

Figure 8 shows a summary of the Resource Utilization for the resources in the area.

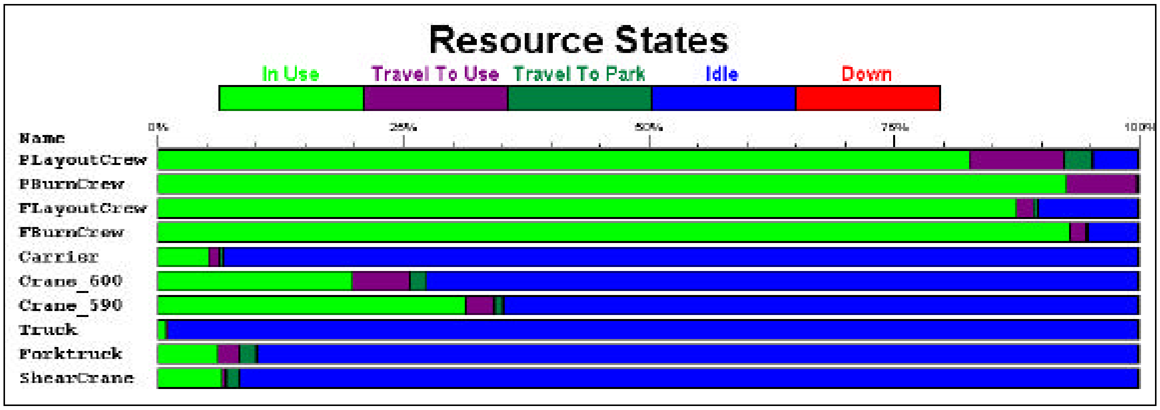


Figure 8: Resource States for "As-Is" Profile Fabrication Area

The 600 and 590 Cranes, Carrier, Truck, Forktruck, and Shear Crane are idle much of the time. These resources are used many times during the process, but only for only a short duration each time. For example, the Carrier enters the bay to drop off and remove batches of raw stock and finished pieces. There is a long time period between entries into the bay and the actual time spent in the bay is only a few minutes. This results in a large amount of idle time in the simulation. It is important, however, to be cautious when drawing conclusions about resources such as the carrier that are shared by other areas not modeled in the system. The true idle time of the Carrier is actually much lower due to its use in other areas of the yard. It is only known from this information that the Carrier will be required in Profile Fabrication Area 5% of it's normal workday.

A similar caution is necessary when analyzing the utilizations of the manning resources in the area. The layout and burn crews in the Flatbar and Roller Table areas have utilizations over 80%. Although a high utilization is desirable, it is possible that because of the manner in which the processes were modeled, these resources may be overutilized when they exceed 85% in-use time. Figure 9 shows the relation of the modeled time versus actual shift time.

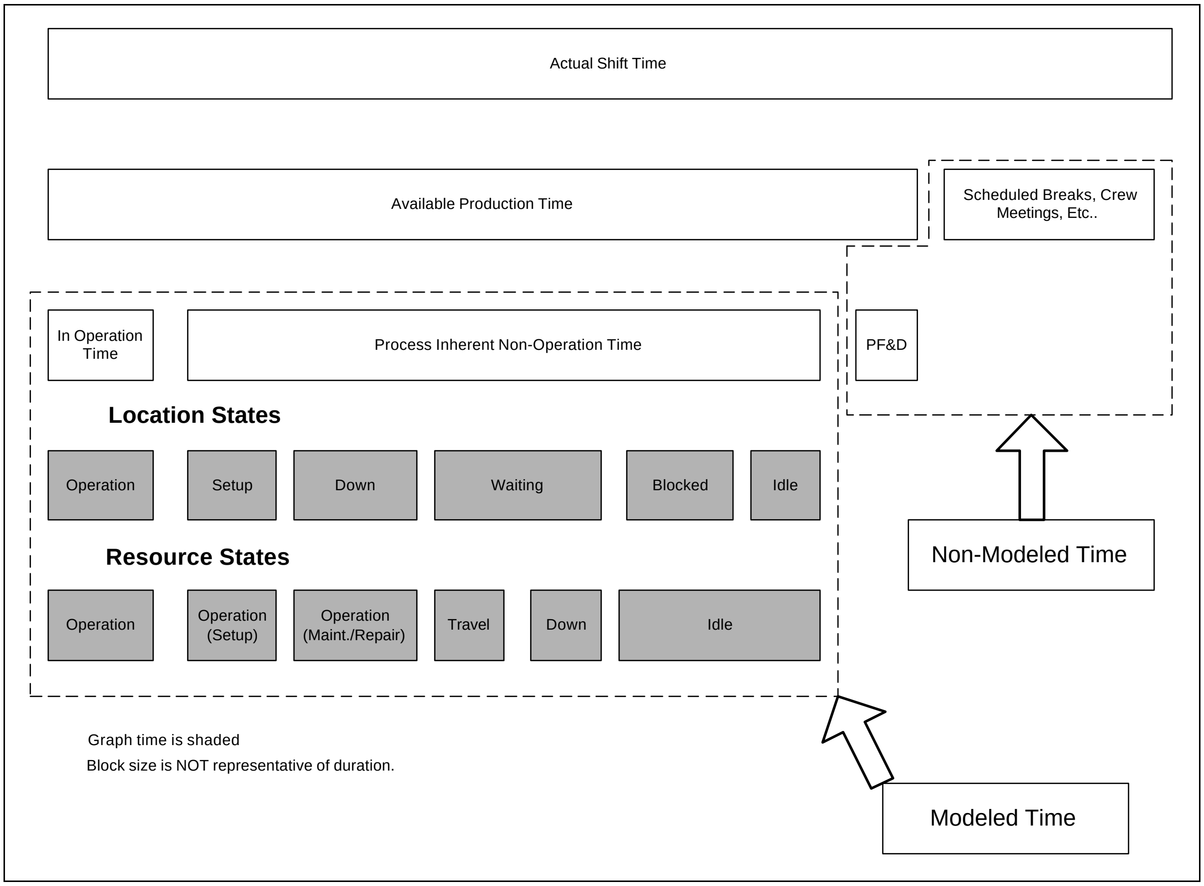


Figure 9: Relation of Modeled Time to Actual Shift Time

Rather than directly adjusting the process times for Crew Meetings and Personal Fatigue and Delay (PF&D), an assessment of the potential overutilization of manning resources can be made by looking at non-operation times on the Resource States graph. If it is assumed that the time necessary for breaks and PF&D amounts to approximately 15% of the actual shift time then those resources with in-use times greater than 85% have the potential of being overutilized. Using this criteria, Figure 8 shows that the Flatbar Layout and Burners and the Profile Burners have the potential for overutilization. Of course, this does not mean that the Profile Layout Crew is not in danger of being overutilized. Since the Resource State graph is a rollup of the entire simulation period, instances of overutilization of the Profile Layout Crew may occur during the running of the simulation that are not reflected in the rollup.

<u>Possible Areas for Automation in Profile Fabrication</u>

Based on the high wait and low operation times, the use of a Robotic Profile Cutter was investigated for area. The Robot would handle both the profiles and flatbar processed in the bay. The Cutting System would theoretically reduce the manpower required to process the product in this area and make better use of the required resources. The main requirement in employing the robot here is that it produce, at a minimum, the same output as currently being produced manually in the same amount of time. This is necessary to support the just-in-time building strategy of the interim products.

6.2 Panel Line

The manning for the Panel Line is shown in Table 3.

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
Fitters	2			5		7			
Deck Socket Welders	2	2							
Welders		2			3		6	6	3
Layout			2						1
Burner			1						
Total	4	4	3	5	3	7	6	6	4

Total on Line	42

Table 3: Per-Shift Manning of "As-Is" Panel Line

The resulting throughput for the Panel Line is shown in Table 4.

Avg Panel Cycle Time	4.04 hrs
Panel Line Span Time	32.7 hrs
Panels Produced	290

Table 4: Throughput Rate for 290 Panels on "As-Is" Panel Line

The Location States for the Panel Line are shown in Figure 10.

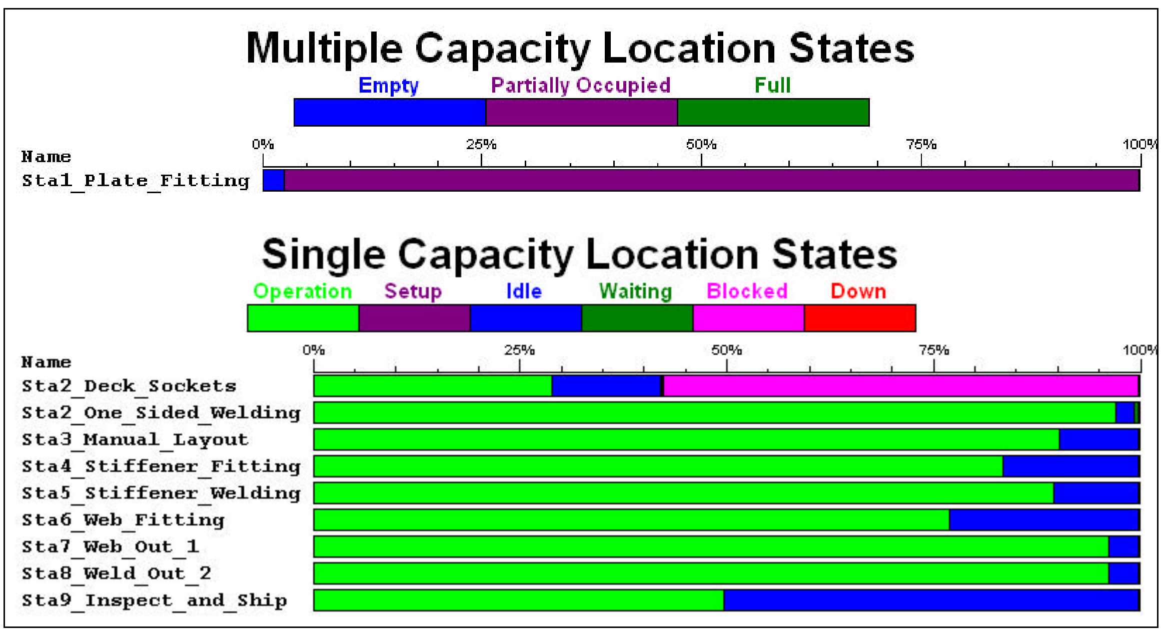


Figure 10: Location States for "As-Is" Panel Line

ProModel distinguishes between multiple and single capacity locations. In the Panel Line, Station 1 is modeled as a multiple capacity location since several plates enter this location to form a Panel. The rest of the stations are single capacity locations because a singular entity (the panel) moves through these areas. As expected, Station 1 is partially occupied 97% of the time due to the fact that plates are entering the station as soon as the preceding panel is moved out. The small bit of empty time is attributed to the stripping of the line near end of the simulation. The graph also does not show any full time since the maximum capacity of the location (10 plates) is not reached during the run.

The Single Capacity Locations, for the most part, all have good operation times. The Station 2 Deck Sockets location is used to model the 50 feet between the end of Station 1 and beginning of Station 2 One-Sided Welding. This extra 50 feet allows a Panel in Station 2 to be backed up in order to clean the flux bar used in the one-sided welding operation. It also acts as a small buffer between the two stations and creates the opportunity to continue the welding of deck sockets left over from Station 1. For these reasons, a high in-use time is not expected for Station 2 Deck Sockets. The blockage in the line is due to the deck socket work that is finishing in this area before the preceding panel is complete in the One-Sided Welding station. Since this part of the line has the shortest cycle time of all of the stations on the line, the blockage is not unexpected. Ideas for making better use of the time in this area once the deck socket work is completed on the panel should be investigated in a more detailed study of the line.

The only other Stations which are not above 80% in-use are Station 6 (which is only slightly below the 80% mark) and Station 9. Station 9 is used to complete weld wraps not completed in Stations 7 and 8, inspect the finished panels, fix any quality deficiencies, and acts as a buffer for finished panels before shipping them to the Assembly Tables. Because inspection does nothing to change the state of the product, the time spent in operation at this station should be kept to a minimum. In fact, Station 9 does have the second lowest usage in the model.

The Resource Utilization for the Panel Line is shown in Figure 11.

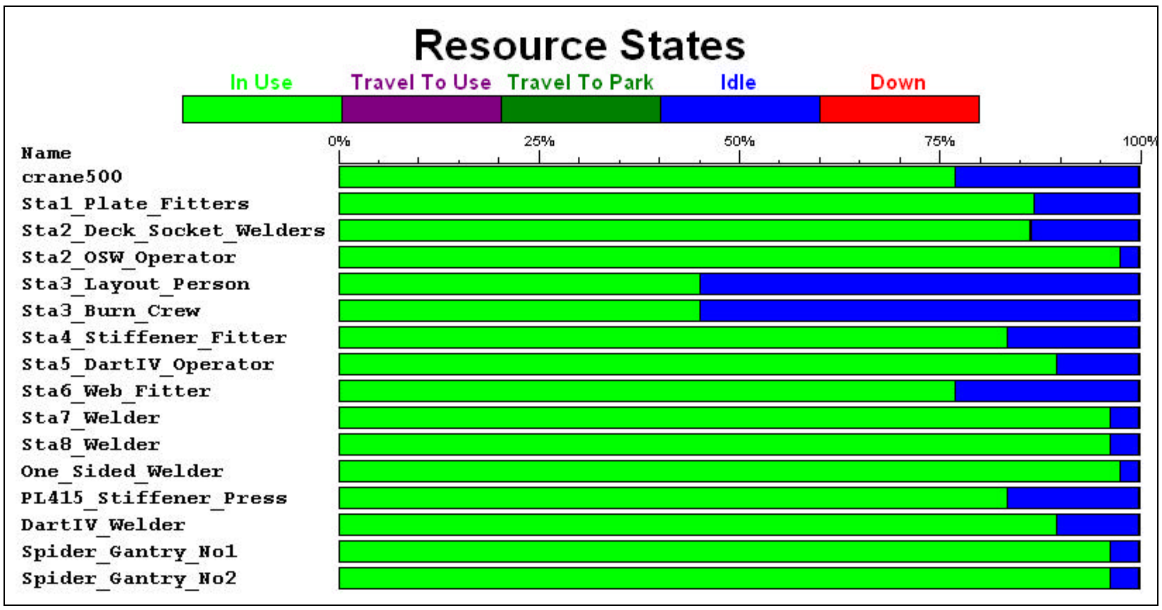


Figure 11: Resource States for "As-Is" Panel Line

The resources on the Panel Line also have a good utilization. Of the resources which are in use less than 80% of the time, the 500 Crane and the Station 6 Web Fitter are in use only slightly less than 80% and the Layout and Burn operations in Station 3 occur in series. The resources for these two operations will therefore show idle time because the usage of the Layout Person is done during the idle time of the Burner and vice-versa. The operation of the Station is equal to the sum of the two.

There are some resources that may be overutilized. The plate fitters in Station 1 (Sta1_Plate_Fitters), deck socket welders (Sta2_Deck_Socket_Welders), one-sided welding operator at Station 2 (Sta2_OSW_Operator), stiffener welding operator at Station 5 (Sta5_DartIV_Operator), Station 7 welders (Sta7_Welder), and Station 8 welders (Sta8_Welder) all have utilizations that are equal to or greater than 85%. Once again, if it is estimated that at least 15% of the process inherent non-operation time is necessary to account for scheduled and unscheduled breaks, then these resources could be in danger of being overutilized in the process and should be investigated in a more detailed study of the area.

Possible Areas for Automation on the Panel Line

Stations 2 and 5 are primarily machine-based operations; therefore, there is nothing in the way of automation that will aid in reducing the high in-use times to open up the line for more work. Methods of reducing the machine operating time will need to be investigated in order speed up the process. The remaining operations are manual and although they are not a constraint to the throughput of the system, provide an opportunity for labor savings. A semi-automatic stiffener fitting gantry for stiffener fitting and a set of gantry-mounted robots in the Station 7 and 8 Weld Out were investigated to assess the potential for labor savings in these areas.

7.0 COLLECT AND COMPILE INFORMATION ON SELECTED AUTOMATED SYSTEMS

Collecting the information for the “To-Be” models, incorporating automation, presents a new set of challenges. First, it is difficult to collect data on a system that may not be designed yet. This is the case with many custom designed automation packages. In addition, the information collected from existing custom designed packages is going to be reflective of the goals and operating practices of the company for which it is designed. The data collected may not be directly applicable to the modeled yard.

Secondly, developing a custom automated system such as a robotic profile cutting system takes time. In many cases, simulation modeling is initially used to make a “go-no-go” decision on whether or not to employ automation. It may be more efficient, therefore, for a yard to draw upon as much standard information as possible from many sources rather than detailing out a system before its use is justified. There are many sources from which this general information can be drawn:

- Manufacturers
- Experience
- Trade magazines
- Textbooks
- Benchmarking trips to manufacturers who employ automation

One of the advantages in going through this process is the insight into the characteristics necessary for an automated system to be successfully utilized in the yard. Questions such as, “What products will be processed using the automation?” and “Is our facility capable of producing the quality input products necessary to feed the automation?” can be addressed and understood before going to the robot manufacturer.

With these factors in mind, some of the information necessary in the “To-Be” models includes:

- Overall robot processing speed
- Number of robots
- Number of operators
- Setup times
- Products to be processed by the robot
- Material handling methods
- Layout
- Cost

7.1 Profile Fabrication Area

Benchmarking trips were made to yards that employ automation to collect information for the “To-Be” models. The layout and flow for the “To-Be” Profile Fabrication Area was developed from a production robotic profile cutter employed at Flensburger Schiffbau-Gesellschaft (FSG) in northern Germany. FSG has built over 700 ships since being established in 1872 and is looking toward automation and new technologies to aid in cost-effectively building ships well into the next century. Their efforts have helped the yard increase productivity from one ship in a year to six. In 1996 FSG purchased a Reis Robotic cutting system from the now-closed BW shipyard in Germany. The cutting system was on-line at FSG within a year of purchase and has proven to be an important part of the production process. On-site benchmarking of the Reis cutting system was done to collect information for the "To-Be" Profile Fabrication Area model. Time studies were done to compile data for the process times, and it was extremely advantageous to have a visual understanding of how the system worked for the building of the model.

In addition to the process times, Statistical Process Control (SPC) and cutting tolerance data was also collected at FSG. This information gave the project team an idea of the quality levels and repeatability of the machine. Finally, the operating procedures and manning were observed to gain an understanding of the resources necessary to operate the cutting system. All of the data was compared to vendor furnished data. This was done to evaluate the performance of a new cutting system against that of system which had been in service for a while. A second Reis cutting system was also observed in operation at Kiel yard of Howaldtwerke-Deutsche Werft AG (HDW) in Germany to further evaluate the performance of a system which had been employed for a number of years. Both the FSG and HDW cutting systems had excellent cutting accuracy for systems that had seen long term use in a production environment. The data that was collected was also comparable to the vendor-furnished data, which showed that the system was capable of maintaining its original performance specifications.

The time study data taken at FSG was adjusted for cutouts that are done at NASSCO but not FSG. NASSCO also processes material, such as angles and heavier bulb plate that is not processed at FSG. The process times for these materials were derived from information provided by Kranendonk Factory automation B.V. for a cutting system similar to that built by Reis Robotics. Both sets of times were similar to each other and the Kranendonk times underwent the same adjustment for cutouts that were not included in the vendor-furnished data.

7.2 Panel Line

Information for the "To-Be" Panel Line model was developed from two initiatives undertaken at NASSCO. In 1997 NASSCO began initial design work on a New Block Assembly Line (NBAL) which would be used to construct flat blocks for various ship types. The NBAL is an assembly line for blocks. Panels are created at the head of the line exactly as they are built on the panel line. Panels are built adjacent to each other and form the upper and lower halves of a double bottom or wing tank block when they are flipped into position by the line's overhead turning crane. The two halves are welded together to form the block, and additional welding of detailed parts such as watertight collars takes place at the end of the line. One of the new processes being investigated for the line was a stiffener mounting gantry which was to be used to semi-automatically place stiffeners onto the panel and tack weld them into position. A cassette of stiffeners for a panel is loaded onto a cart that follows the mounting crane carriage. At the proper point on the panel the carriage stops and a stiffener is removed from the cart by the crane and placed into position on the panel. Once in position, the stiffener is tacked down using two tack welding heads that move along the length of the crane gantry. The stiffener mounting system was developed by Ingenieurtechnik and Maschinenbau Gesellschaft (IMG) for the NBAL. The layout and process times for the gantry were used directly in the Panel Line model.

As part of a project sponsored by the United States Maritime Administration (MARAD), NASSCO and CYBO Robotics have partnered to develop a beta-test, welding robot for the Panel Line. The robot's primary function is to weld out the transverse web frames on deck panels and any lugs or collars included with the frame. Although the robot is being developed for the Panel Line, it has a portable set up that allows it to function beyond captured Line use. On the Panel Line, the track on which the robot moves rests on top of the longitudinals and runs parallel to the web frame. Once the track is manually set in position, the robot runs a series of macros to weld the frame that indicate what type of features are on the web and how they are to be welded. During the welding process, sensors keep the welding head at the proper position along the frame.

The process times for the web welding in the "To-Be" Panel Line model were developed from the test times for the CYBO robot. The operation of the robot in the "To-Be" model was altered, however, in order to include some features that would be better suited to the long-term operation of the Line. Instead of using one robot, six robots are used in each weld out station (Station 7 and 8) of the "To-Be" model to take advantage of the time savings in welding out several web frames simultaneously. In addition, these robots are mounted on an overhead gantry rather than using the tracks necessary to run the CYBO robot. This eliminates the need to set up six individual tracks on each panel. When using the track-mounted robot, the tracks have to be placed in position and manually aligned before the robot can find the starting position. By using an overhead gantry the robots can be lowered from overhead, find the starting position, and begin welding, thus saving the time necessary for manual adjustment of the tracks. Odense is currently using a system similar to this on their panel line in Denmark.

8.0 MODEL AREAS WITH AUTOMATION

The models incorporating automation are modeled in much the same manner as the existing area. Material is modeled so that it isn't a constraint to the system. Downtimes are also not modeled.

8.1 Profile Fabrication Area

The layout of the new Profile Fabrication Area incorporating the robot is shown in Figure 12.

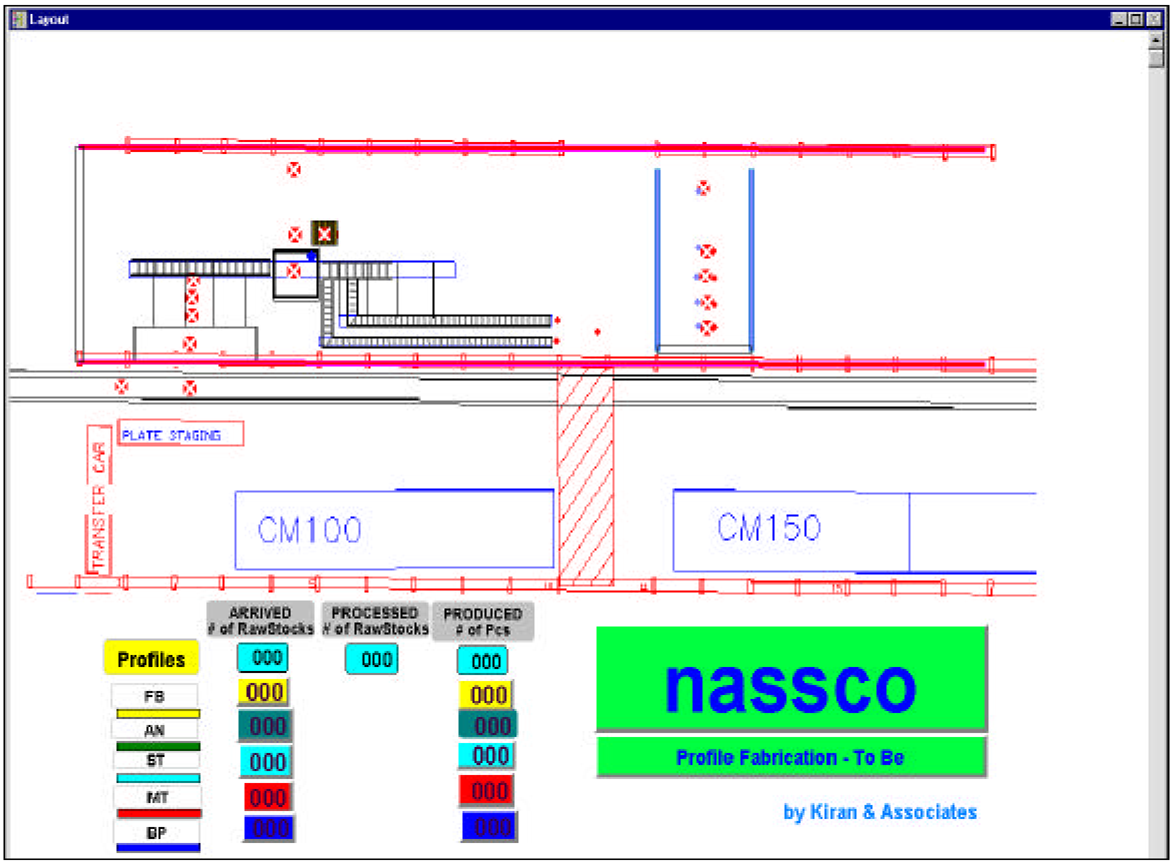


Figure 12: Layout for "To-Be" Profile Fabrication Area

In order to facilitate the movement of material to the robot, a collocator and conveyor system was included in the new "To-Be" model. The collocator now brings batches of raw flatbar and profiles into the area directly from the output conveyor of the Blast and Prime Line. The raw material is kept in a small buffer until there is space on the input conveyor for the robot. The transfer of the material between the buffer and input conveyor is done automatically through a chain and roller mechanism. The raw stock is processed by the robot, and the parts are output to one of three possible locations depending upon the size of the part. Small parts are ejected into a basket where they will be sorted by hand onto the proper pallet. Medium and large parts are sent down separate conveyors where they will be lifted by an overhead crane and placed in the appropriate cassette by next assembly. Each cassette is then lifted onto a transporter by a second overhead crane and moved to the appropriate build location. The pallets of small parts are moved by forktruck to the appropriate build location or storage. The number of finished pieces cut from each raw stock is based on the same triangular distribution used in the "As-Is" Profile Fabrication model and represents the variation in finished product. The manning is constant. The processing times are also constants and based on the average processing time for the specific material type.

8.2 Panel Line

The layout for the new Panel Line is shown in Figure 13.

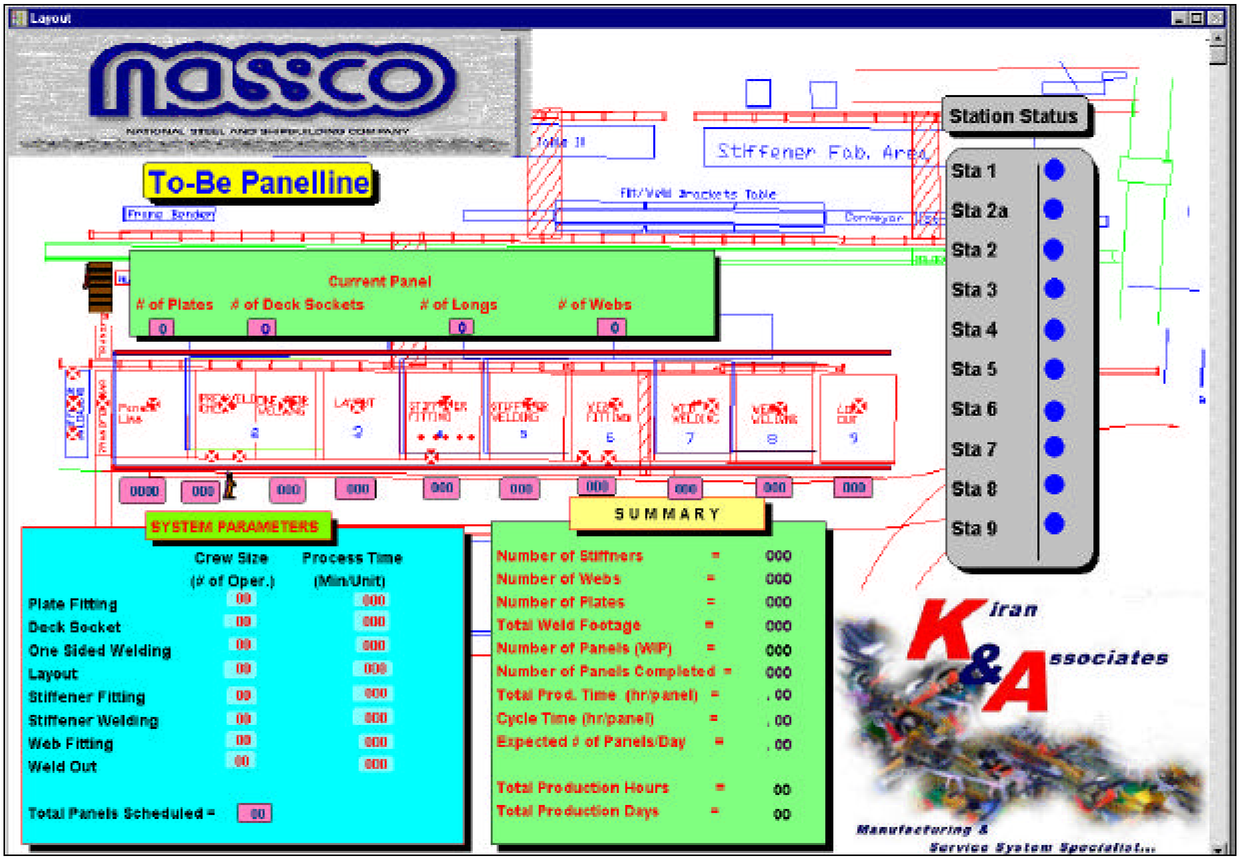


Figure 13: Layout for "To-Be" Panel Line

The new, "To-Be," model for the Panel Line is essentially the same as the existing Panel Line model. Station 4, however, now uses the stiffener fitting gantry for the fitting of longs and stiffeners on a panel. Station 7 and 8 Weld Out areas each use a set of six gantry-mounted robots in order to perform the final weld out of transverse webs in the "To-Be" model. The panels on the line are the same standard panels used to represent the average panel work content in the "As-Is" Panel Line model. Finally, both the process times and manning levels for each station are constants.

9.0 DETERMINE IMPACT OF AUTOMATION

Once the programming of the models is completed and they are validated for accuracy, the experiments can begin. The types of experiments that are done depend on the objective of the study and detail of the models. It is best to outline how the experiments are going to be run during the building of the models, however, many computer simulation software packages have features whereby variables such as manning can be changed quickly without reprogramming. This adds an additional level of flexibility to the model in terms of possible experiments that can be run.

9.1 Performance

The experiments conducted for this project consisted of optimization of the models and a comparison between the “As-Is” and “To-Be” models. As mentioned earlier, the models were optimized to make best possible use of the area’s resources. ProModel uses “run-time interfaces” which allows the modeler to quickly change resource levels and material input. The changes were an interactive process where several models were run with different levels of manning and material input to determine the level that:

- Made the best possible use of resources and locations in the “As-Is” and “To-Be” models (taking into account any constraints on the system)
- Produced a throughput in the “As-Is” model that was representative of the throughput currently seen (or planned) in the actual area being modeled.
- Allowed for a direct comparison between “As-Is” and “To-Be” models.

The results of the final experiments for the “To-Be” model, and the comparison to the results from the “As-Is” model runs, is discussed in the following sections.

9.1.1 Profile Fabrication Area

Table 5 shows the manpower and resulting output for the “To-Be” Profile Fabrication area incorporating the robotic profile cutter.

Manning in Model	
Area Operators	2

Arrivals	
Profile Raw Stock	3816
FlatBar Raw Stock	3682
Total	7498

Parts Produced	
Profiles	6942
FlatBar	17708

Table 5: Per-Shift Manning and Throughput for 840 Production Hours in “To-Be” Profile Fabrication Area

The “As-Is” model used 6791 raw stock pieces of profiles and flatbar to create 22567 parts. The “To-Be” model used 7498 raw stock profiles and flatbar to create 24650 parts. This is an increase of throughput of approximately 10% when using the robot over the existing method of processing profiles and flatbar. This result confirms that the new profile area will produce enough parts to meet the current demand filled by the existing Profile Fabrication area. The processing will be done with 1/10th of the people utilized in the existing “As-Is” model (2 operators in the “To-Be” model vs. 17 in the “As-Is” model).

The Location States for the “To-Be” model are shown in Figure 14.

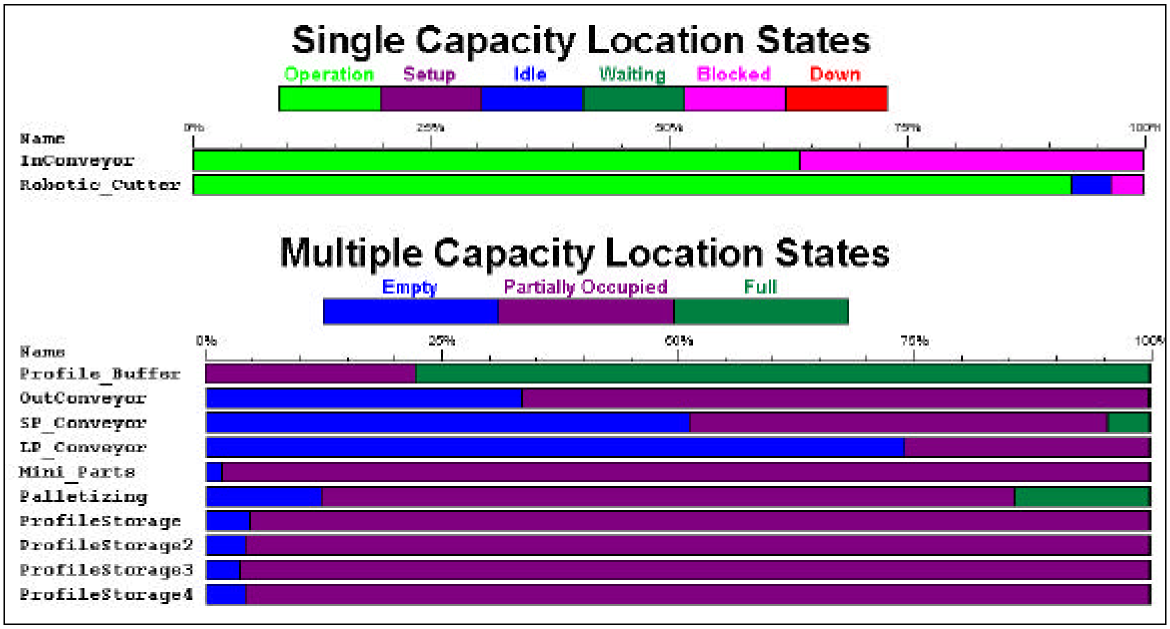


Figure 14: Location States for "To-Be" Profile Fabrication Area

The input conveyor (InConveyor) for the robot shows some blockage. This is to be expected since the raw stock sits on the conveyor until the previous raw stock being processed by the robotic cutter is complete. The robot (Robotic_Cutter) is in use over 90% of the time. Assuming that one person is needed to be near the robot during operation, then the manning resource may be in danger of overutilization. Observations of the manning levels for the robot at FSG and HDW, however, indicated that two to three operators in the area of the robot was sufficient to keep up with normal production. These operators were rotated to allow for scheduled and unscheduled breaks so that at least one person is monitoring the robot during operation. Therefore, a usage of over 90% does not indicate overutilization of the resources. There is a small amount of blockage (less than 5%) occurring as the robot tries to move a finished part onto the output conveyor. This may be an indication that the buffer size of the output conveyor may need to be increased, but because it is less than 5%, it can be considered negligible for the purposes of this study. The idle time shown for the Robotic Cutter is due to the startup and stripping of the Profile Cutting System.

The main issues on the Multiple Capacity Location States graph are the locations which are full for a percentage of the time since these areas can be constraints to the system or cause blockages. The profile buffer (Profile_Buffer) is full over 75% of the time. Since we are modeling the system under the assumption that the material is never a constraint to the process, it is good that the buffer is either partially occupied or full 100% of the time. The fact that it is full 75% of the time, however, may be an indication that the buffer size should be increased or the frequency of batches of raw stock from the Blast and Prime Line decreased (may not be possible due to production demands) in order to prevent the line from backing up the Blast and Prime operations.

The medium part (SP_Conveyor) and palletizing area for small parts (Palletizing) also are full a percentage of the time. The full palletizing location should not be a problem since these parts come from the collection basket for small parts under the cutting area of the robot (Mini_Parts) which holds multiple parts without blocking the operation of the robot. Since the Mini_Parts location is partially occupied almost 100% of the time, however, this area might require a more detailed look in a later study to determine if a problem with material movement here exists. The 5% full time for the short part conveyor (SP_Conveyor) can be considered negligible for the purposes of this study. A more detailed analysis of the material handling system should be done at a later time to assess the impact of the full conveyors and buffers to the overall throughput of the Line.

The utilizations for the "To-Be" Profile Fabrication Area resources are shown in the Resource Utilization graph in Figure 15.

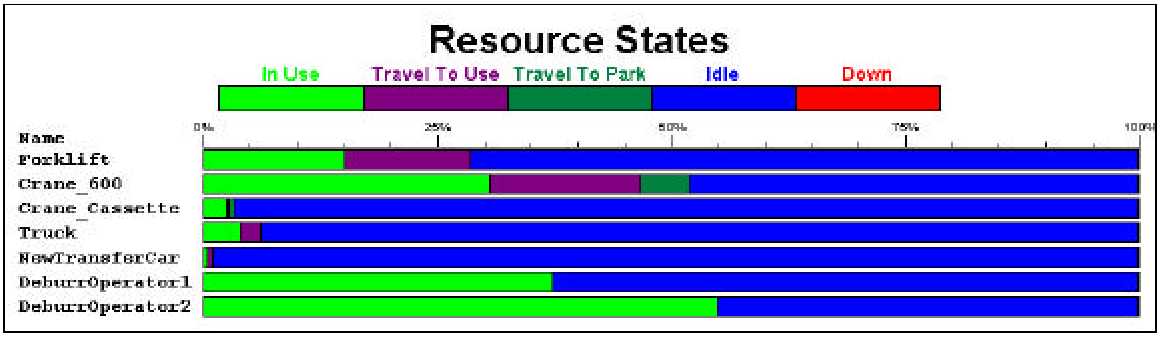


Figure 15: Resource States for "To-Be" Profile Fabrication Area

There is no problem with resource overutilization in the "To-Be" Profile Fabrication area. As in the existing Profile Fabrication Area model, most of the resources such as the forklift, and cranes are used for a short duration with periods of idle time in between the uses. The two deburr operators (DeburrOperator1 and DeburrOperator2) are required in this area based on observations made while the Project Team was at FSG and HDW. The actual utilization of these resources will be slightly higher due to the need for one person to investigate problems that may occur with the robot outside of normal operation. A third operator could do the deburring and palletizing of small parts while monitoring the robot. If this alternative is chosen, the idle time shown for DeburrOperator1 and DeburrOperator2 would be as indicated while the utilization of the third operator would be less than that of the robot (since the robot does not require human assistance full time).

Assessment of Automation Performance

Based on the performance indicated by the results of the "To-Be" Profile Fabrication Area model it is recommended that the Profile Cutting Robot be considered for the replacement of the existing Profile and Flatbar processing system. The robot provides the same throughput as the existing system in a smaller area with 1/10th the people employed in the "As-Is" process. The "To-Be" system also has a better material flow as shown in Figures 16 and 17. The automated profile cutting operation is a fairly straight-line process without much human contact.

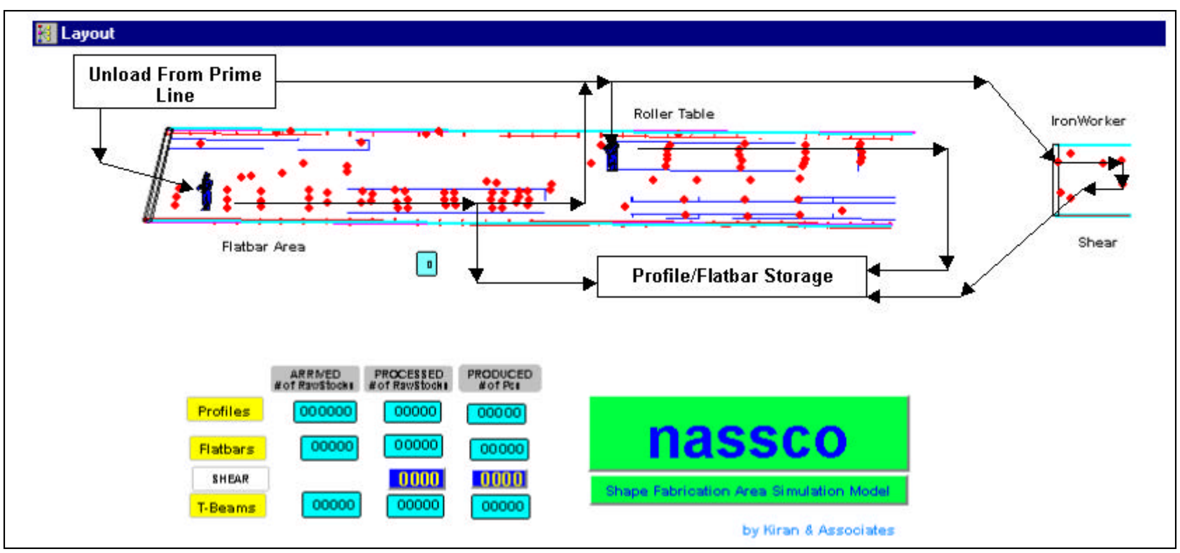


Figure 16: Material Flow in Existing "As-Is" Profile Fabrication Area

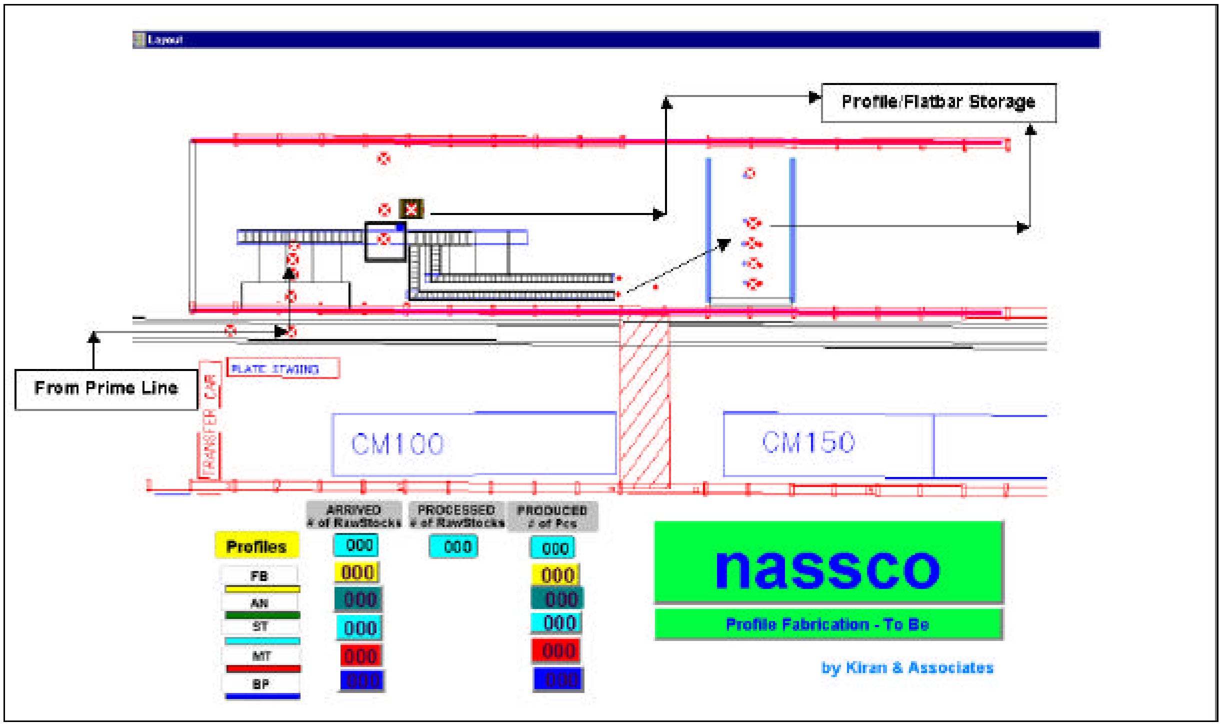


Figure 17: Material Flow for "To-Be" Profile Fabrication Area

9.1.2 Panel Line

Table 6 shows the manpower and resulting throughput for the Panel Line with a stiffener fitting gantry and twelve weldout robots welding at a rate of 12.5 minutes/intersection (derived from Cybo robot tests).

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
Fitters	2			1		7			
Deck Socket Welders	2	2							
Welders		2			3		1	1	3
Layout			2						1
Burner			1						
Total	4	4	3	1	3	7	1	1	4

Total on Line	28

Avg Panel Cycle Time	4.03 hrs
Panel Line Span Time	29.9 hrs
Panels Produced	290

Table 6: Per-Shift Manning and Resulting Throughput for "To-Be" Panel Line

Through the use of the automation in Stations 4,7,and 8, the manning on the Line has been reduced from 42 to 28 (33% difference). The cycle time is slightly lower (less than1% difference) and can be considered to be equal to that in the "As-Is" model. The panel line span time is 9% lower in the "To-Be" model. The lower span time means that the first panel assembled after starting up an empty line will finish 2.8 hours earlier. After the completion of the first panel, a completed panel will be removed from the line every 4.03 hours. A substantial amount of manning, therefore, has been removed from the line through the use of automation without affecting throughput.

The Location States for the Panel Line are shown in Figure 18.

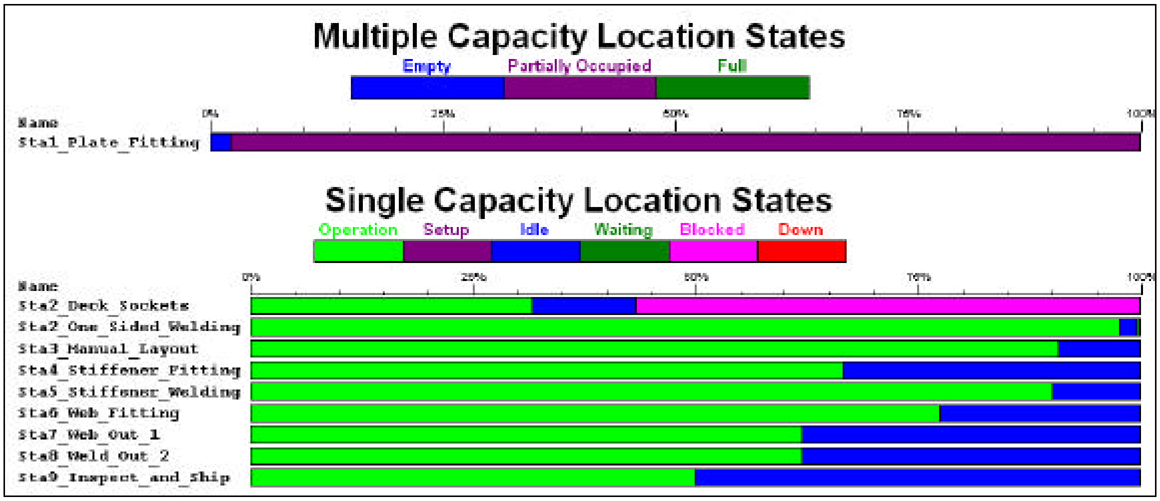


Figure 18: Location States for "To-Be" Panel Line

Stations 1 through 3 and 5, 6 and 9 have the same operation and partially occupied times as those in the "As-Is" model. The operation time of Station 4 has dropped from 84% in the "As-Is" model to 66% in the "To-Be" model. The increase in idle time in this station is due to the faster rate at which stiffeners are fit using the stiffener fitting gantry. The use of the stiffener fitting gantry allows more work to be done in this station with 4 less people than in the "As-Is" model. The same effect can be seen in Station7 and 8 where the operation time has dropped from 95% to 62%. In order to take advantage of the additional capacity in Station 4, 7 and 8, however, the time each panel spends in Station 2 and 5 will have to be reduced. As mentioned earlier, because the processes in these stations are primarily machine based, the reduction in station time in these areas will have to happen through reducing the welding rates of the machines.

The Resource States for the area is shown in Figure 19.

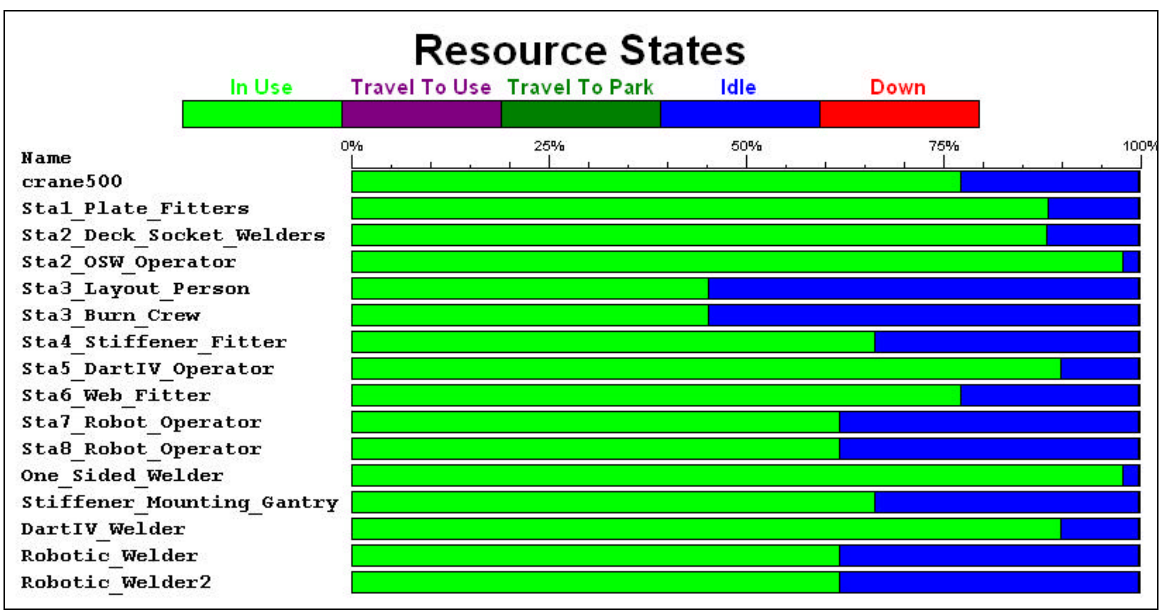


Figure 19: Resource States for "To-Be" Panel Line

The resource usage in the “To-Be” model is equal to that in the “As-Is” model for those stations in which automation was not added. Some of the resources are above 85% in use. This indicates that there is a possibility for overutilization of these resources. These areas should be investigated further in more detail to make sure that the high utilizations are not an issue.

Station 4, which had a decrease in operation time due to the addition of the automation, also had a decrease in the utilization of the Station’s resources (Sta4_Stiffener_Fitter). The robot operators in Station 7 and 8 also have utilizations that are lower than the Station 7 and 8 Web Welders in the “As-Is” model.

<u>Panel Line Performance with Equal Station Capacities</u>

The lower resource utilization means that, in addition to reducing the manpower on the line, the automation also increased the potential capacity of Stations 4, 7, and 8 due to the reduced amount of time each panel spends in these stations. In order to create the same condition in the “As-Is” model, additional manning is necessary. Therefore, to gage the additional manning required to achieve the faster station span time (and increased station capacity), the “As-Is” model was run with increased manpower in Stations 4, 7, and 8. The “As-Is” manning level that provided the same throughput and Location/Resource usage as the “To-Be” model is shown in Table 7.

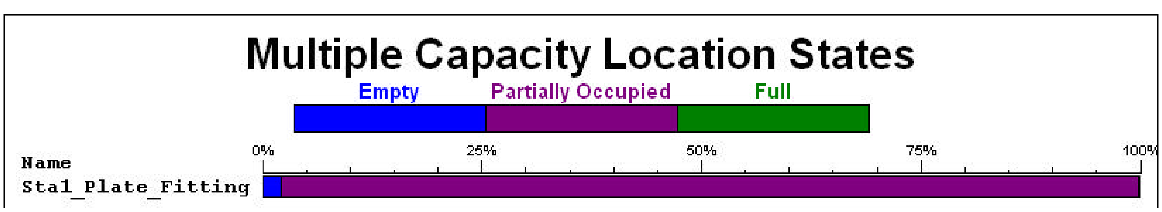
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
Fitters	2			7		7			
Deck Socket Welders	2	2							
Welders		2			3		9	9	3
Layout			2						1
Burner			1						
Total	4	4	3	7	3	7	9	9	4

Total on Line	50

Avg Panel Cycle Time	4.06 hrs
Panel Line Span Time	29.7 hrs
Panels Produced	290

Table 7: “As-Is” Model Manning Level Adjusted for Model Comparisons With Equal Station Span Times

Eight additional people are needed in the “As-Is” model to accomplish the same station throughput as in Stations 4, 7, and 8 of the “To-Be” model (2 additional fitters in Station 4 and 3 additional welders in both Station 7 and 8). The Location and Resource States for the “As-Is” model are shown in Figures 20 and 21. The graphs indicate that the Operation and In Use times of the Locations and Resources are equal to those of the “To-Be” model (Figures 18 and 19). The introduction of the stiffener fitting gantry and weldout robots to the Panel Line, therefore, creates a labor savings of 44% over the “As-Is” Panel Line if the span times in each station are required to be equal.



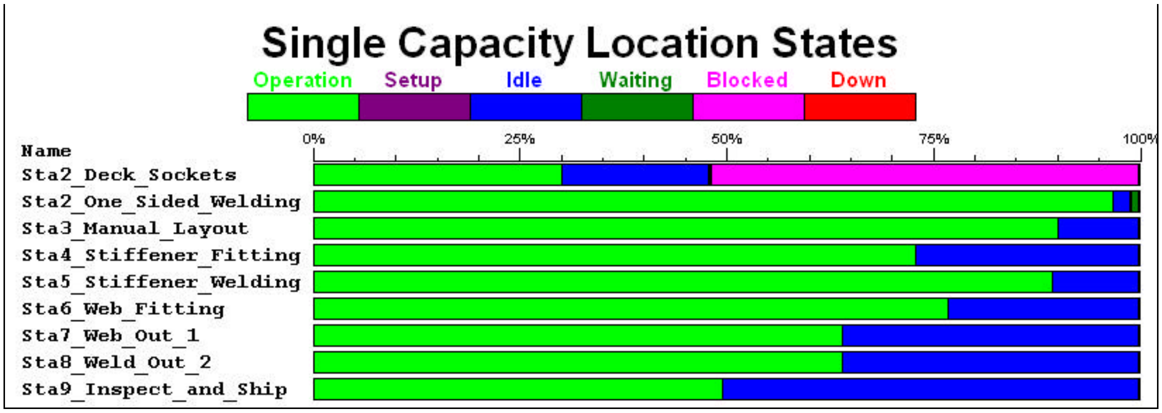


Figure 20: Location States for "As-Is" Model with Adjusted Manpower

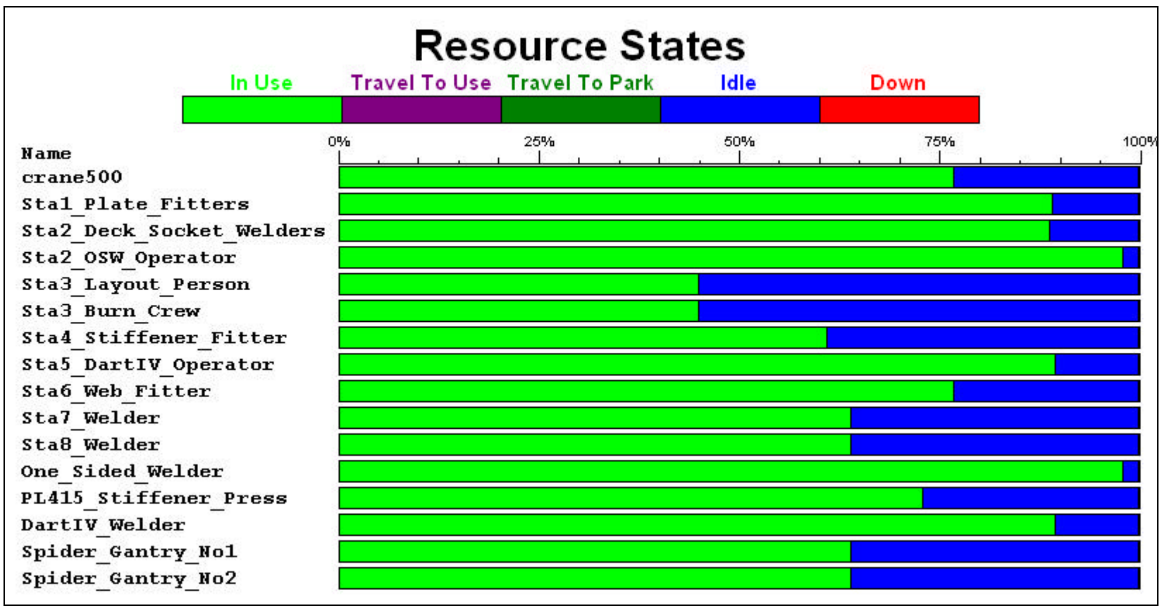


Figure 21: Resource States for "As-Is" Model with Adjusted Manpower

Panel Line Performance with Stiffener Fitting Gantry and Six Web Weldout Robots in Station 7

From a cost and resource utilization standpoint, it would be desirable to complete the welding of the webs in one station rather than two. A series of experiments were run to determine the necessary welding rate that would allow the weldout of a 5 web panel with six robots (the maximum that can operate in one station). The results of the experiments indicated that time necessary for 6 robots to complete the welding of the panel in Station 7 was 9.75 minutes/intersection. The manning and throughput when six robots with the faster welding rate are utilized in Station 7 is shown in Table 8.

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
Fitters	2			1		7			
Deck Socket Welders	2	2							
Welders		2			3		1		3
Layout			2						1
Burner			1						
Total	4	4	3	1	3	7	1	0	4

Total on Line	27

Avg Panel Cycle Time	4.03 hrs
Panel Line Span Time	28.8 hrs
Panels Produced	290

Table 8: Manning and Throughput When Six Robots Are Utilized in Station 7

The manpower was reduced by one person since the operator for the 6 robots in Station 8 is no longer needed. The Location and Resource States for the Panel Line with robots in Station 7 is shown in Figures 22 and 23.

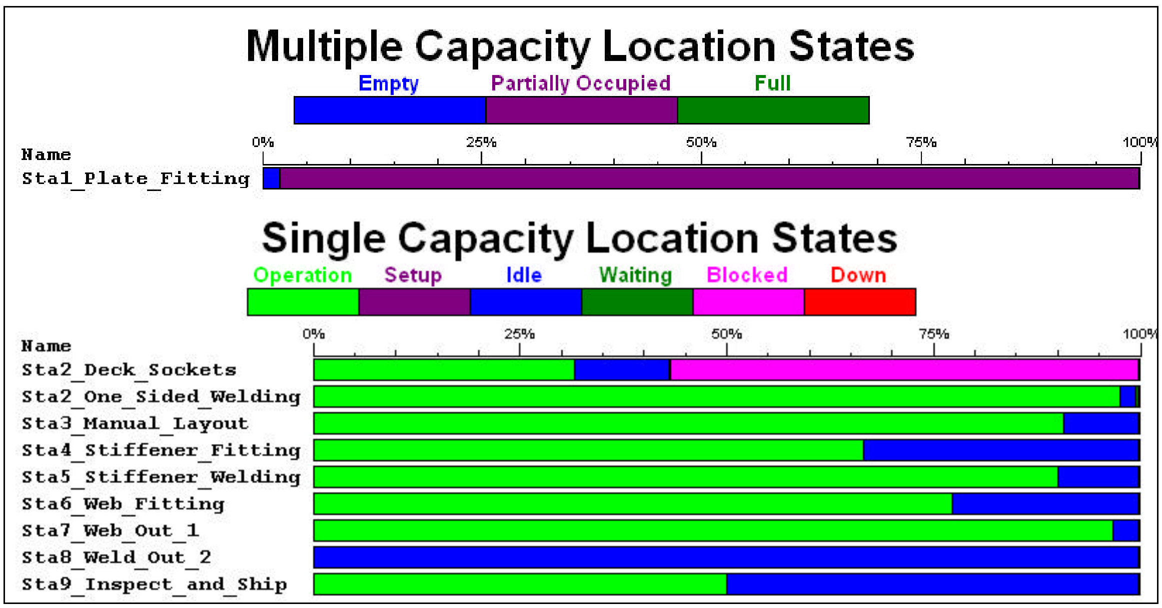


Figure 22: Location States for the Panel Line with Robots in Station 7

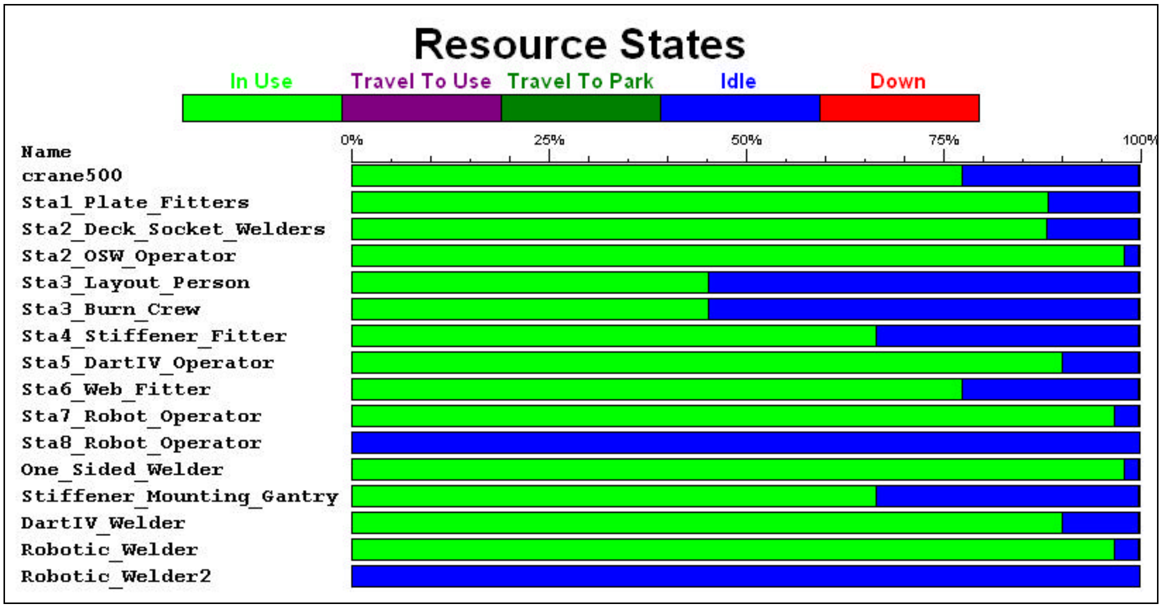


Figure 23: Resource States for Panel Line with Robots in Station 7

Figures 22 and 23 show a much better use of the Station 7 location and resources, although there should be further investigation to determine if the operator is overutilized. Station 8 is now idle 100% of the time since no work is being done in this Station. An additional advantage to using only the six robots in Station 7 for panel weldout is that the investment cost for welding robots has been cut in half. Of course, it also means decreased capacity for the Weldout Stations. The robots are in operation almost 100% of the time. Should the throughput be increased through Station 2 and 5, the robots in Station 7 will become the constraint to the line unless the welding rate of the robots is further decreased or a second set of 6 welding robots is added to Station 8.

Assessment of Automation Performance

Employing a stiffener fitting gantry and 12 web weldout robots on the Panel Line significantly decreases manning by 33%. The throughput rate for the "To-Be" line is the same 4 hours as the "As-Is" Line with 14 less people. The utilization of the resources in the automated stations also dropped. This lower utilization means that there is the potential for increased throughput in these stations. In order to increase the throughput through the same stations in the "As-Is" model, additional manning is necessary. To get an estimate of the total manpower saved when the increased capacity is taken into account, additional manning was added to the "As-Is" model until the utilization of Stations 4, 7 and 8 was equal to that in the "To-Be" model. It would take an additional 2 fitters in Station 4 and an additional 3 Fitters in both Station 7 and 8 in the "As-Is" model to equal the station throughput rates in the "To-Be" model. The savings in manpower over a similar "As-Is" line with the same throughput rates, therefore, is 44% (50 people in the "As-Is" model reduced to 28 in the "To-Be" model).

In an effort to reduce investment costs while increasing the utilization of the robots in the "To-Be" model, several experiments were run to determine the robot welding rate that would allow 6 robots in one station (the maximum that can be operated in one station) to complete the panel weldout. The results indicated that a rate of 9.75 minutes/intersection would be sufficient to complete the work without affecting line cycle time. When this rate is used, the manning of the "To-Be" line is further reduced from 28 to 27. The investment cost for the weldout robots is significantly reduced since only one set of robots needs to be purchased, and the utilization of the robots is much greater. The payback calculations are discussed in section 9.2.2.

Based on the performance results of the "To-Be" Panel Line model, it is recommended that at least six gantry mounted robots and stiffener-fitting gantry be used in place of the existing manual operations in Stations 4 and 7 of the "As-Is" Panel Line. The manning in this scenario is reduced by 36% without affecting overall Line throughput. If the capacity of Station 7 is an issue, then a second set of 6 gantry-mounted robots should be used in Station 8 to increase the throughput of both stations. The automation, in this case, will reduce the manning by 33% over the "As-Is" Panel Line or 44% over an "As-Is" Line with equal throughputs in Stations 4, 7, and 8.

9.2 Payback

The payback for the purposes of this project is calculated using the capital cost of the equipment and the savings in labor for both the Profile Fabrication area and Panel line. Additional costs such as consumables for the payback period, depreciation of equipment, and applicable taxes are not used in this high level analysis; however, they should be studied once the analysis has given an indication of whether or not to proceed.

9.2.1 Profile Fabrication Area

The calculation of the payback period for the "To-Be" Profile Fabrication area is shown in Table 11.

	"As-Is"	"To-Be"
Simulation Run Time (hrs)	840	840
Total Raw Stocks Processed	6791	7498
Total Parts Produced	22567	24650
Total Manning	17	3
Resouce Cost ($/hr)	32	32
Hours Per Year	2000	2000
Labor Cost per Year ($)	1088000	192000
Savings Over "As-Is" ($/year)	n/a	896000
Profile Fabrication Robot Cost ($)	n/a	2000000
Payback (years)	**n/a**	**2.23**

Table 9: Payback Calculation for "To-Be" Profile Fabrication Area

It will take a little over 2 years to recover the cost of the robotic profile cutting line based on the labor savings alone. This is a reasonable payback period for this type of equipment and it is recommended, based on the payback for the robot, that this system be used in place of the existing profile fabrication process.

9.2.2 Panel Line

The payback calculation for the "To-Be" Panel Line is shown in Table 12.

Variables	"As-Is"	"To-Be"
Stiffener Fitting Manning	5	1
Weldout Station 1 Manning	6	1
Weldout station 2 Manning	6	1
Weldout Robot Time (per intersection)	n/a	12.5 min
Results		
Total Manning	42	28
Simulation Run Time (hrs)	1174.24	1168.52
Panel Cycle Time (hrs/panel)	4.05	4.03
Panels Per Day	3.96	3.97
Resource Cost ($/hr)	32	32
Labor Hours per Year	2000	2000
Labor Cost per Year ($)	2688000	1792000
Savings Over "As-Is" ($/ship)	n/a	896000
Stiffener Fitting Gantry Cost ($)	n/a	1000000
Web Welding Robot Cost ($)	n/a	3500000
Total Automation Cost ($)	n/a	4500000
Payback Period (years)	**n/a**	**5.02**
Equipment		
Sta 4 IMG Stiffener Fitting Gantry		x
Sta 7 - 6 Weldout Robots		x
Sta 8 - 6 Weldout Robots		x

Table 10: Payback Calculation for "To-Be" Panel Line

Because of the cost of the automation in the "To-Be" Panel Line scenario, the payback period for the equipment is 5 years. Of course, the savings in labor seen by the yard after five years is almost $900,000/year, which is a significant savings. This calculation also does not take into account the additional capacity in Stations 4, 7, and 8 when automation is introduced.

<u>Payback Taking Into Account Increased Capacity</u>

If the increased capacity in Stations 4, 7 and 8 is taken into account, and the "As-Is" model is adjusted for that station throughput, the payback for the "To-Be" is shown in Table 11.

Variables	"As-Is" High Throughput	"To-Be"
Stiffener Fitting Manning	7	1
Weldout Station 1 Manning	9	1
Weldout station 2 Manning	9	1
Weldout Robot Time (per intersection)	n/a	12.5 min
Results		
Total Manning	50	28
Simulation Run Time (hrs)	1183.57	1168.52
Panel Cycle Time (hrs/panel)	4.08	4.03
Panels Per Day	3.92	3.97
Resource Cost ($/hr)	32	32
Labor Hours per Year	2000	2000
Labor Cost per Year ($)	3200000	1792000
Savings Over "As-Is" ($/ship)	n/a	1408000
Stiffener Fitting Gantry Cost ($)	n/a	1000000
Web Welding Robot Cost ($)	n/a	3500000
Total Automation Cost ($)	n/a	4500000
Payback Period (years)	**n/a**	**3.20**
Equipment		
Sta 4 IMG Stiffener Fitting Gantry		x
Sta 7 - 6 Weldout Robots		x
Sta 8 - 6 Weldout Robots		x

Table 11: Payback Calculation for "To-Be" Model when Compared To the "As-Is" model with the Same Station Throughputs

The payback period drops to just over three years due to the larger reduction in manning when increased capacity is taken into account. The labor savings is $1.4 million/year.

Payback for Stiffener Fitting Gantry and Six Weldout Robots in Station 7

Finally, if the welding rate of the robots is reduced to 9.75 minutes/intersection, so that the weldout of the panel can occur entirely in Station 7, the payback in Table 12 is achieved.

Variables	"As-Is"	"To-Be" One Station Web Weldout
Stiffener Fitting Manning	5	1
Weldout Station 1 Manning	6	1
Weldout station 2 Manning	6	0
Weldout Robot Time (per intersection)	n/a	9.75 min
Results		
Total Manning	42	27
Simulation Run Time (hrs)	1174.24	1167.42
Panel Cycle Time (hrs/panel)	4.05	4.03
Panels Per Day	3.96	3.97
Resource Cost ($/hr)	32	32
Labor Hours per Year	2000	2000
Labor Cost per Year ($)	2688000	1728000
Savings Over "As-Is" ($/ship)	n/a	960000
Stiffener Fitting Gantry Cost ($)	n/a	1000000
Web Welding Robot Cost ($)	n/a	1750000
Total Automation Cost ($)	n/a	2750000
Payback Period (years)	**n/a**	**2.86**
Equipment		
Sta 4 IMG Stiffener Fitting Gantry		x
Sta 7 - 6 Weldout Robots		x
Sta 8 - 6 Weldout Robots		

Table 12: Payback for Automation of Station 4 and Station 7

The payback period drops to less than three years, and the labor savings changes to $960,000/year when compared to the "As-Is" Panel Line. The 9.75 minutes/intersection weld rate will most likely be achieved through the reduction of sensing time the robot uses to take in factors related to its environment. Most of these factors are related to the fitup of the web to the other members on the panel. Improving the fitup, therefore, reduces the need for the robot to collect this information, and thus reduces the welding rate for the process.

Recommendations Based on Payback Calculations

Based on the $900,000 to $1.4 million/year savings in labor (depending on automation scenario chosen) it is recommended that an investment be made in the automation of the stiffener fitting and web weldout operations. If capacity of the Web Weldout Stations is not an immediate issue, six weldout robots should be purchased for Station 7 first. This will shorten the payback period for the automation to 2.86 years, make better utilization of the robot as a resource, and provide the ability to add additional robots to handle greater capacity should it become necessary to do so. In addition, there are other advantages to employing automation discussed in Section 9.3 that generate additional savings throughout all stages of construction. These savings are difficult to capture in the simulation (and are not modeled in the above Panel Line simulations), however, they contribute significantly to the bottom line of building a ship.

9.3 Other Advantages in Automation

Although this report shows that automation plays a major role in the reduction of labor hours associated with the fabrication and assembly of steel products, it is interesting to note that the leading yards in the application of automation such as Odense in Denmark, and Mitsubishi in Japan, employ it for reasons other than direct labor savings. The primary drivers for introducing automation in these yards are to reduce construction span times, increase production predictability and decrease process variation, enforce discipline and accuracy control on non-automated operations, and transfer critical labor skills to technological capabilities.

9.3.1 Reduction of Construction Span Time

Automation reduces construction span time. The use of robotics allows for cell-level assembly and welding operations. The operations are done in fewer stations, which reduces the amount of material handling, block moves, and necessary interim products. This results in a shorter construction time for the block. Automation also forces a need for design standardization. Each change in the design from contract to contract necessitates the reprogramming of the automation to be able to handle the change. Standardization of the design is necessary to eliminate reprogramming, and this in turn shortens the span time of the ship design process. Rather than creating each design from scratch, designers create from a list of standard products, thus eliminating "custom" pieces and numerous product families.

9.3.2 Increase Production Predictability and Decrease Process Variation

Not only does automation reduce the variation in ship design; it also reduces the variation in the product that is processed by the automation. The effects of differences in equipment quality, build location, skill level, and personal preferences, occurring in areas such as the Profile Fabrication area are eliminated because the work goes through the same machine every time. The reduced variation means more consistent quality in the product, which reduces or eliminates the need for rework due to defects. The reduced variation and repetitiveness of automation also means a higher degree of predictability in the operations. This makes it easier to plan the day-to-day flow of work through the fabrication or assembly area and allows for greater confidence in the setting of reduced overall span time goals.

9.3.3 Enforcement of Discipline and Accuracy Control of Non-Automated Operations

In order to maintain the repeatability of automation and provide for efficient operation, the input product needs to be fabricated to a certain level of quality and this level must be maintained consistently. Automation is becoming more adaptive as new technologies are applied; however, it is not as adaptive as a human being in performing the same processes. A welder is able to handle variations in weld gap, straightness, and environmental conditions as the welding process is taking place without necessarily having prior knowledge of the variation. Robots are not as adaptive. Rather than viewing this as a negative, however, many of the world's leaders in the application of shipyard automation see this as an enormous advantage. The common view in these yards is that reduced variability and exacting tolerances built into the product throughout the entire construction process will contribute to a savings which far exceeds the cost necessary to maintain the tolerances and reduced variability themselves. For these yards, the advantage of adaptability in human beings brings with a it a certain level of variation due to differences in how two people may adapt differently to the same situation. This difference may even be seen in the same person from day-to–day or instance-to-instance. The variation (which increases the cost of the final product) is not handled well by the automation. Therefore, in order to maintain a smooth transfer of product between manual and automated processes, the workers must perform the work with a higher level of repeatability themselves. The product needs to be built to the specifications and tolerances defined because the automation will not be able to adapt to or repair products that do not meet the standard. An increased adherence to tolerances and a high degree of repeatability, therefore, will be built into both the automated and manual processes.

9.3.4 Transfer of Critical Labor Skills to Technological Capabilities

A fourth advantage of automation is the ability to use it to control the workforce level within the yard. Because of the nature of shipbuilding, there is an inevitable hiring/layoff cycle that yards go through from contract to contract. This cycle makes it difficult to maintain a pool of qualified, skilled labor for shipbuilding. To counteract this problem shipyards are forced to either maintain a steady workload large enough to keep several thousand people in a medium-sized yard employed (difficult to do because of the cyclic nature of shipbuilding) or institute massive training efforts, including on-the-job training, to qualify newhires for shipbuilding tasks. Automation provides yards with a third option. By transferring critical, repetitive, trade skills to database-driven machines the need for large swings in employment is eliminated. Rather than laying-off, the yard is able to reassign smaller numbers of workers to other areas of the yard where needed. The yard is able to retain their skill base and the worker retains his or her job. This concept can also be used in day-to-day operations. The manning curve of a typical shipyard has many peaks and valleys that require the manager of the operation to have to seek out additional labor during a peak and find jobs for many during a valley. This process can be very time-consuming. Automation allows the manager to run the process at a slower or faster rate without affecting the manning of the operation. The same people needed to operate the automation (in many cases fewer than necessary for the same manual operation) are required regardless of whether the process is running at low, half, or full speed. This eliminates the need for job reassignments and makes it easier to plan and budget for labor within the shipyard.

9.3.5 Safety

Added safety is another advantage for shipyards in using automation. Although shipyards go to great lengths to ensure the safety of their employees, the use of a robot in functions such as burning and welding allow the added advantage of positioning the operator at a safe distance from the actual process area. This eliminates the possibility of being burned by slag or a near-by co-worker. Many of these remotely-operated systems have safety features such as light curtains that stop the operation if the process area is accidentally entered. Such safety precautions, in many cases, can provide the added benefit of increasing throughput through a smaller area. For example, throughput in the Profile Fabrication area is constrained because burning, layout, and loading/unloading operations cannot take place in the same set of rows. Therefore, the raw stock must sit on the tables until it is safe to perform the process. In the case of a robotic profile cutting system, however, all of these processes can take place almost simultaneously on the same raw stock in the same area. The ability to safely perform all of these operations at once eliminates the need for safety space buffers between operators and increases the throughput through a smaller area.

9.4 Overall Model

As a final step in understanding the effect automation has on the Steel Fabrication and Subassembly Areas an Overall model was created. The layout of the model is shown in Figure 24. The model's main purpose was to ensure that sub-optimizing the individual areas such as the Profile Fabrication Area and Panel Line would not cause any problems in the rest of Steel Fabrication or Subassembly.

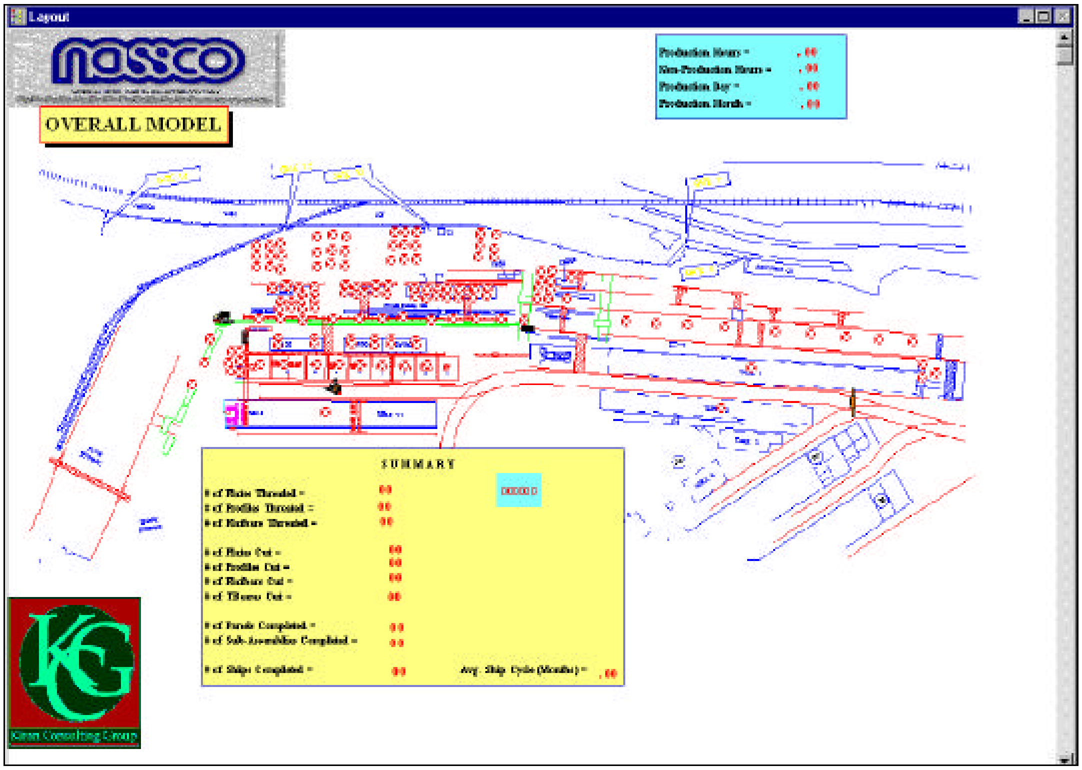


Figure 24: Layout of Overall Model

Data is used from the individual Steel Fabrication and Assembly models to drive the process times and products within the Overall model. The resources utilized between areas, such as cranes and forktrucks, are also modeled. Preliminary results from the Overall model show that the Blast and Prime Line is a key bottleneck to the system. Without developing ways to speed up the Blast and Prime Process (i.e.; purchasing a new blast and prime system, reducing the downtime, or increasing the number of raw stock pieces treated in a pass), the automation will not be utilized to the greatest extent possible.

10.0 NEXT STEPS

Simulation's role in the investigation of the areas suitable for automation doesn't end with the recommendation of areas to automate. The operation of the automated areas needs to be studied in more detail to refine the process, determine buffer sizes, and look for opportunities for further process improvement.

10.1 Profile Fabrication Area

The next step in investigating the possibility of using automation in the Profile Fabrication area is to begin looking at the profile fabrication process involving the robot in more detail. The cutting process should be modeled to include:

- Clamping time
- Raw stock travel time
- Cutting time by part size and cut type
- Marking time
- Setup time
- Down times

The simulation should proceed in conjunction with the detail design of the automated system in order to ensure the optimal process for the yard's production goals and operating procedures.

10.2 Panel Line

Based on the results of the model the next step in detailing the "To-Be" Panel Line is to model, in conjunction with the detailed design of the automation, additional Panel Line processes such as:

- Setup times
- Downtimes
- Special welding or fitting details necessary for the automation to handle
- Detailed estimates of weld pick up and additional manual welding
- Variation in panel work content

Variation in panel work content is a significant detail in the simulation of the line. For a preliminary understanding of how automation affects the line it is possible to use the average panel work content. There must be a realization, however, that panels with a higher work content will slow the throughput of the line while panels with a lower work content will increase the overall throughput. Because of the interactions between the stations that make up the line, the averaging of the high and low work contents will not necessarily equal the throughput of an actual schedule for the line. For this reason it is very important to understand the effects of variation in work content while designing the automation which will be included in the line.

Once more detail has been included in the individual models, the results should be run through the Overall model to ensure that the processes are not being sub-optimized to the benefit the local area at the expense of the efficient operation of the overall yard.

11.0 CONCLUSIONS

Based on the findings of the project team, automation can greatly reduce the labor costs in the Profile Fabrication area and Panel Line. By utilizing a robotic profile cutter in the Profile Fabrication area, the same throughput of the existing manual system can be achieved with an 88% reduction in manpower. The savings are achieved after a reasonable payback period just over 2 years.

A significant labor savings is also achieved on the Panel Line, however, the payback period to recover the cost of the automation is longer than that of the Profile Fabrication Area. If a stiffener fitting gantry and 12 gantry-mounted weldout robots are added to the line, a labor savings of almost $900,000 per year is achieved with a payback period of 5 years. If the additional capacity the automation provides in the fitting and weldout stations is taken into account the payback period drops to just over 3 years. The payback period is significantly lowered if the welding rate of the robots is reduced from 12.5 minutes/intersection to 9.75 minutes/intersection and only 6 robots are necessary for the weldout of a panel. This reduction is quite possible through reducing the sensing time necessary for the robot to track a path along the web. The sensing is necessary to help the robot weld variations in the fitup of the web from nominal; therefore, with better fitups the sensing time is lowered.

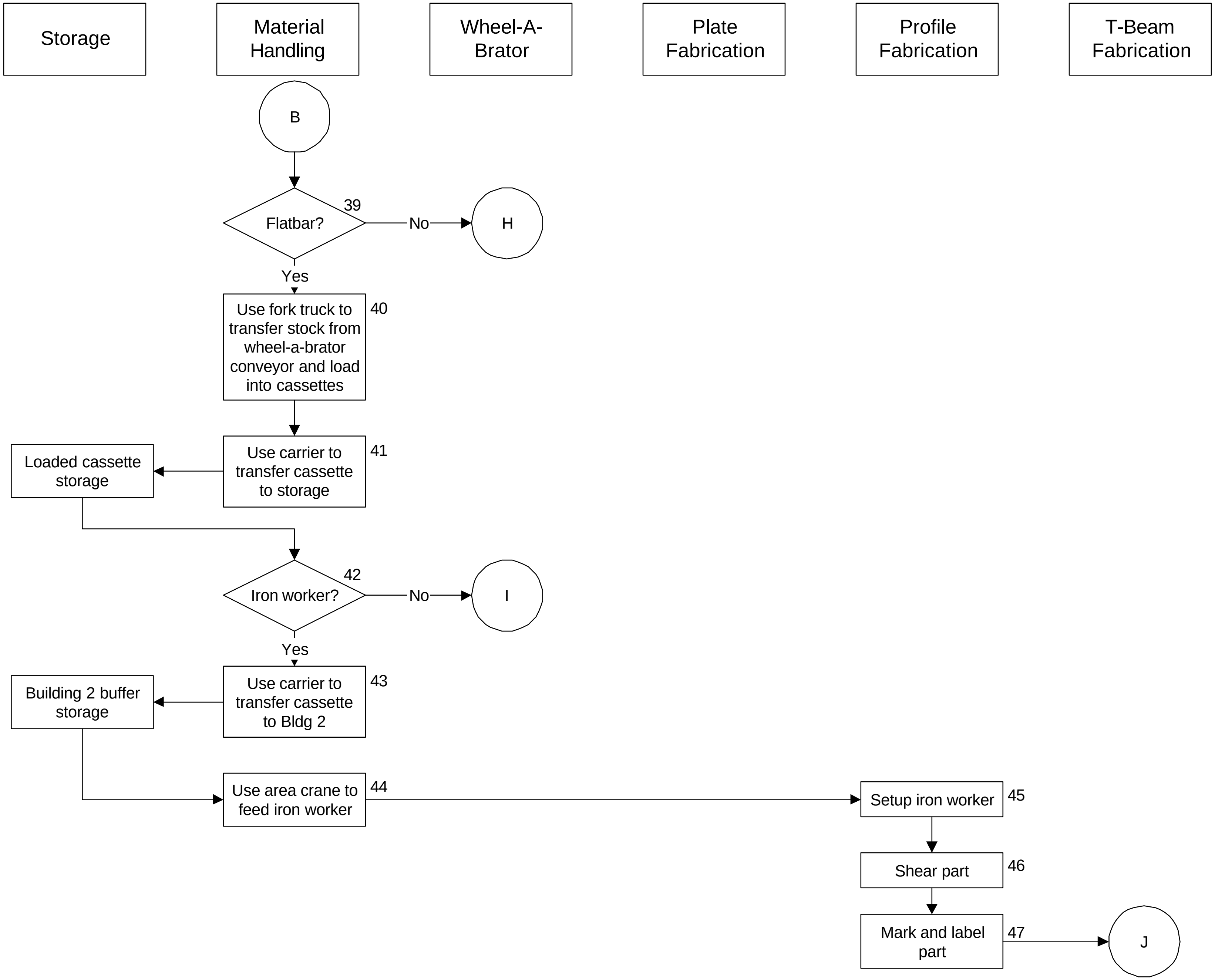
There are additional advantages to using automation in these areas beyond reduced labor costs. The leading yards in the application of automation, in fact, view these advantages as a greater value than the direct savings of labor. The primary drivers for introducing automation in these yards are to reduce construction span times, increase production predictability and decrease process variation, enforce discipline and accuracy control on non-automated operations, and the transference critical labor skills to technological capabilities. These advantages are difficult to quantify in terms of dollar savings using the simulation software, but they definitely contribute to the overall savings in the construction of the ship.

The use of computer simulation gave the project team an advantage in analyzing the possible automation options. The process of creating a computer simulation forced the project team to understand the existing process in great detail. The insight into the process was so great, in fact, that it initially seemed unnecessary to simulate the process. When changes were made to the process or multiple processes were occurring simultaneously, however, the real power of computer simulation became evident. Once the initial model of the existing process was completed, changes to the model such as adding robots or conveyor systems could be accomplished in minutes and the results of the changes were observed immediately. The computer kept track of all of the processes, their times, and products; therefore, the use of variable parameters such as the number of parts per raw stock or processing time was easily handled. In most cases it would be impossible for a project team to be able to perform the same analysis to such a level of detail.

The functionality of computer simulation extends beyond determining suitable areas for automation in Steel Fabrication and Subassembly. Its uses range from the optimization of existing systems to forecasting future problems in conceptual yard layouts. It can be utilized as a cost justification tool or a way of training employees in new processes. With the ability to perform such tasks at a level of detail far greater than could be done manually, and the opportunity to gain results quickly, shipbuilders will have a definite advantage through the use of computer simulation. An advantage that will translate into cost competitive ships in the future.

APPENDIX A

NASSCO Stage of Construction 1 - Steel Fabrication 'As-Is' Process Flowchart



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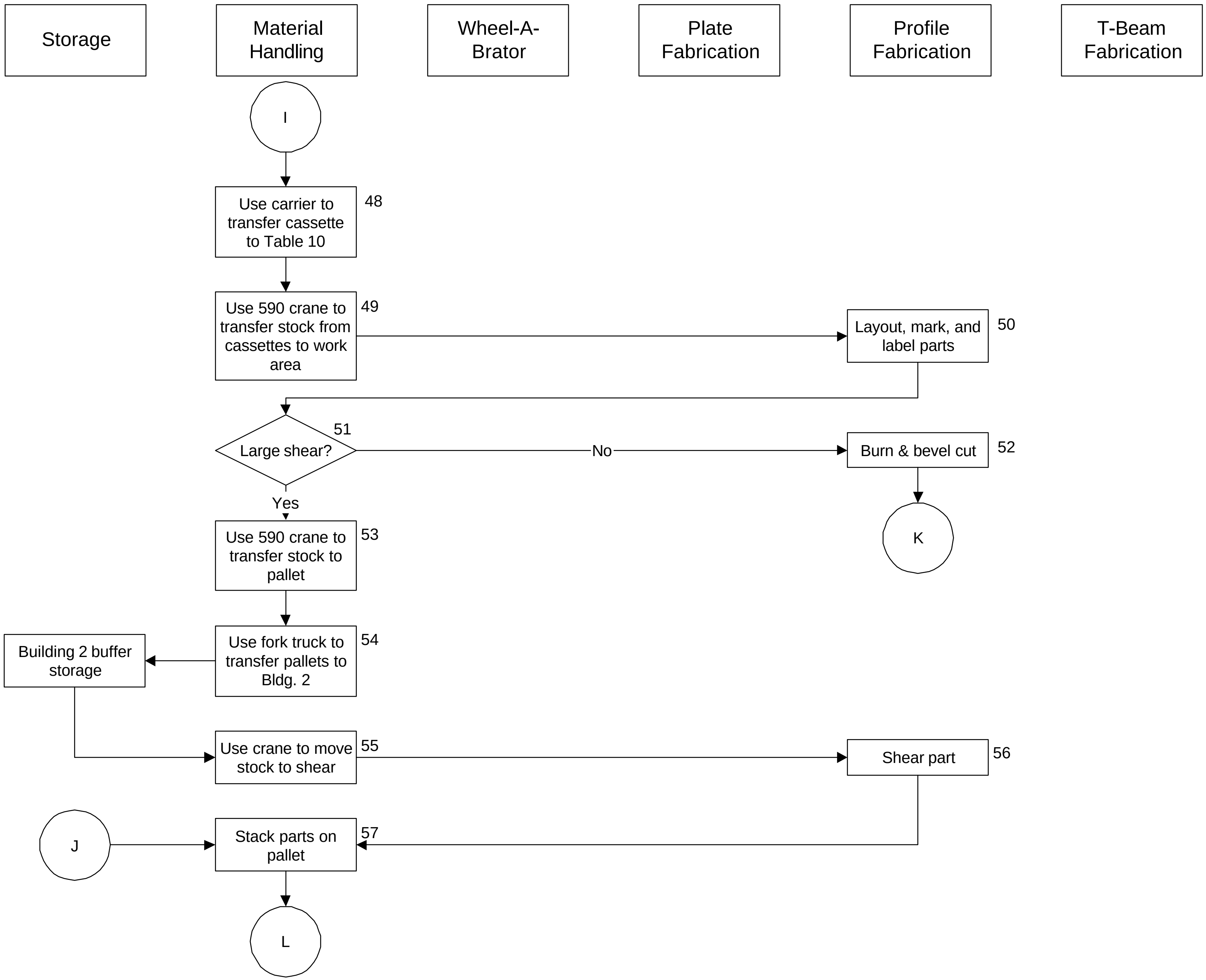

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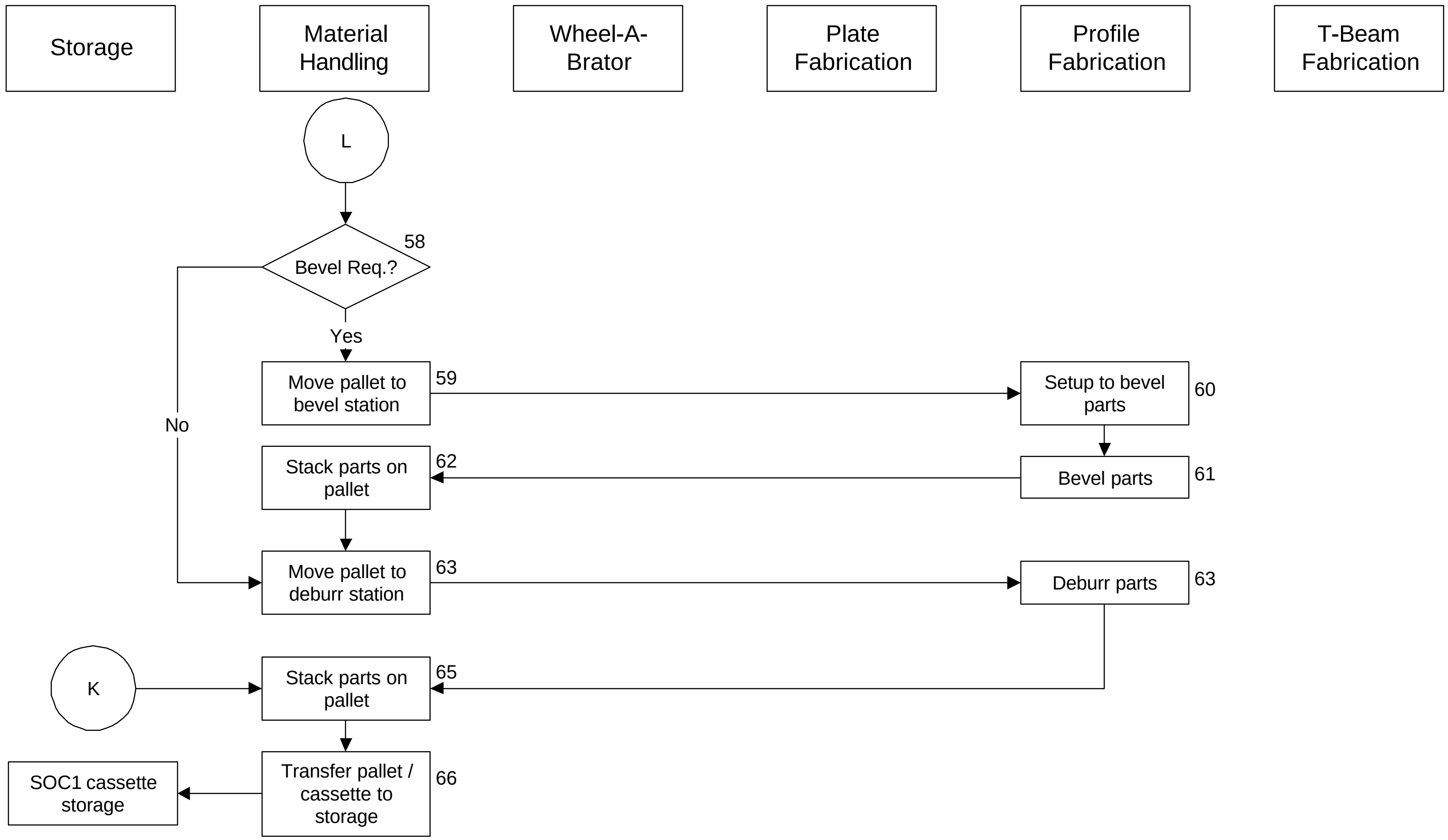

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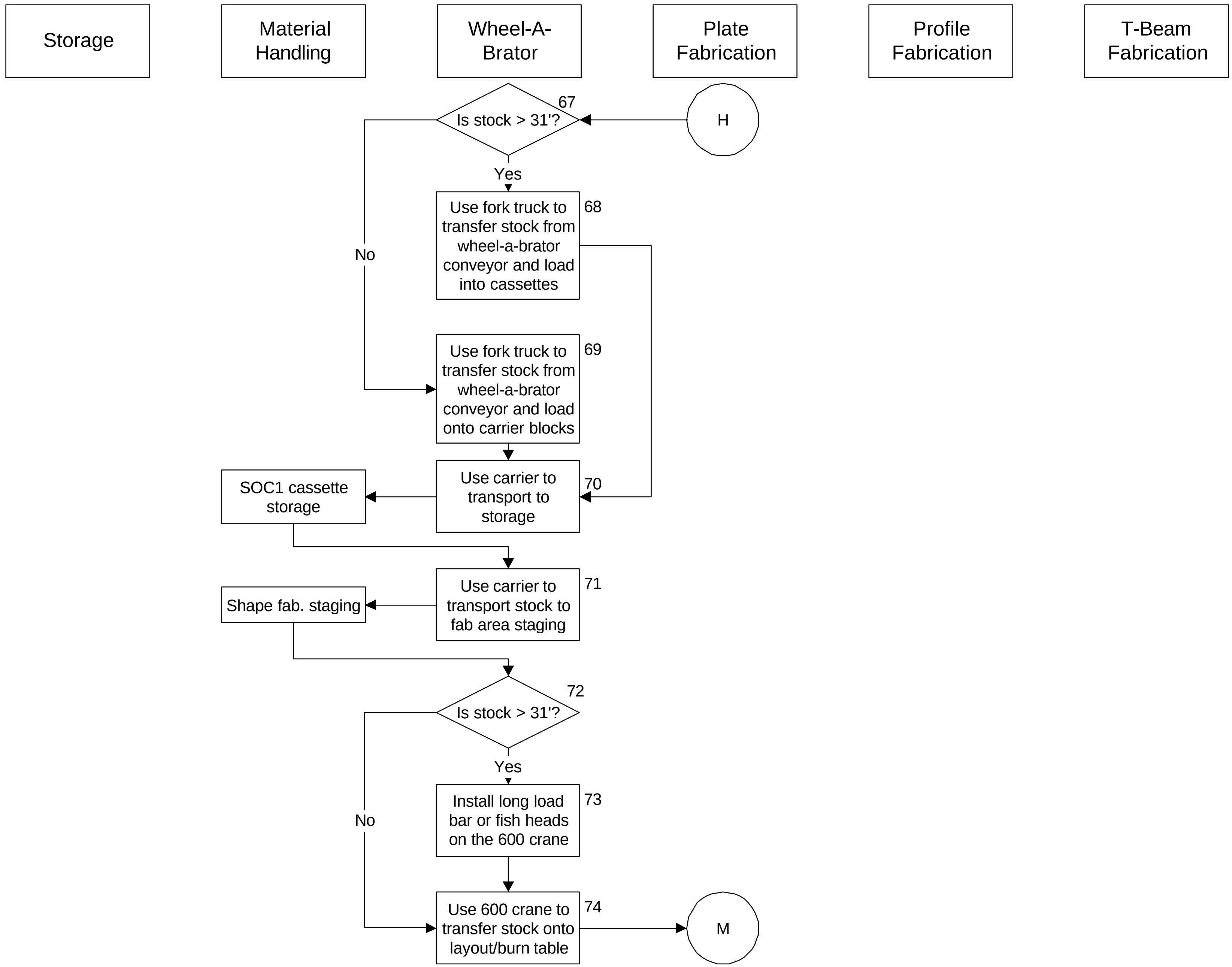

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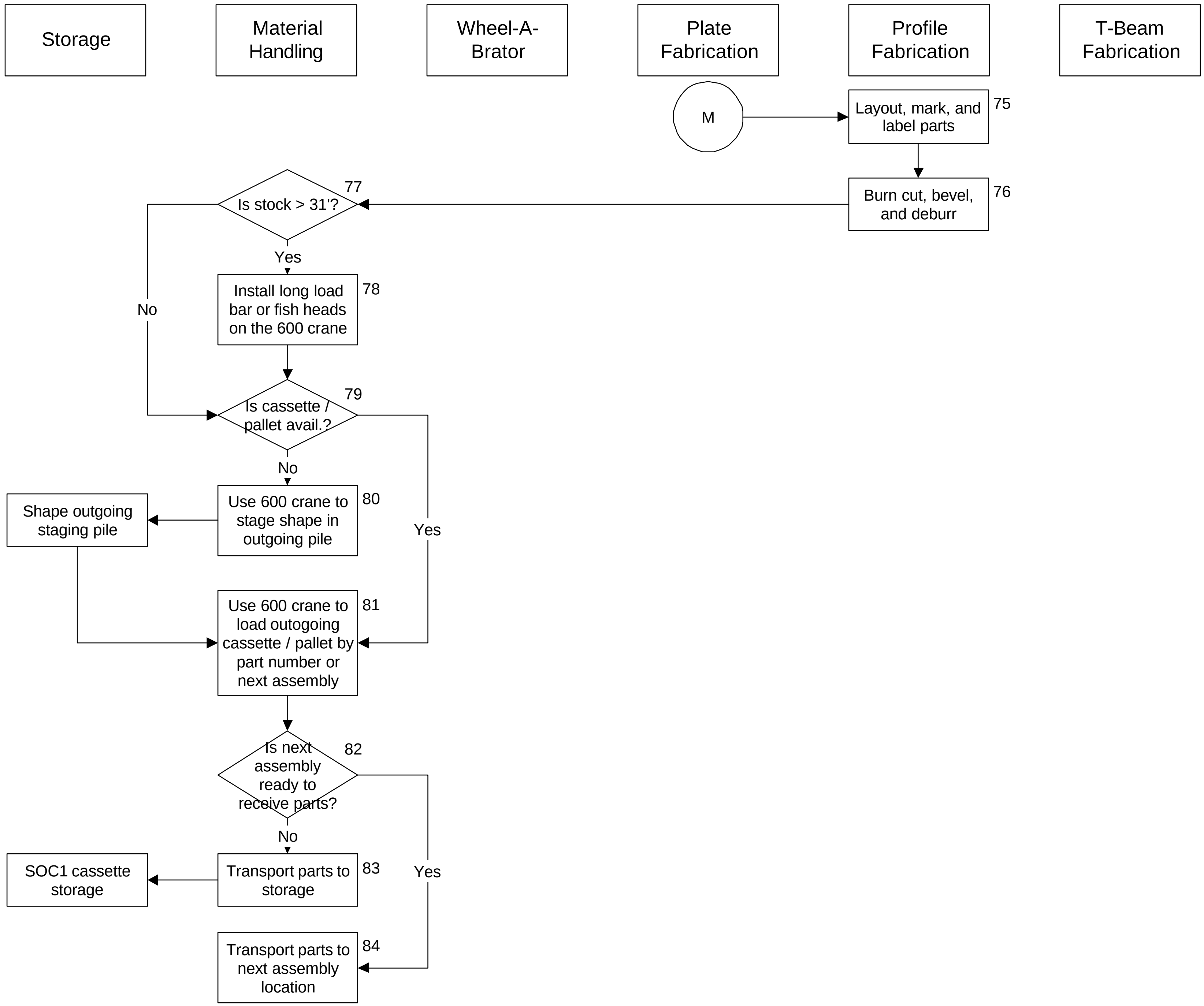
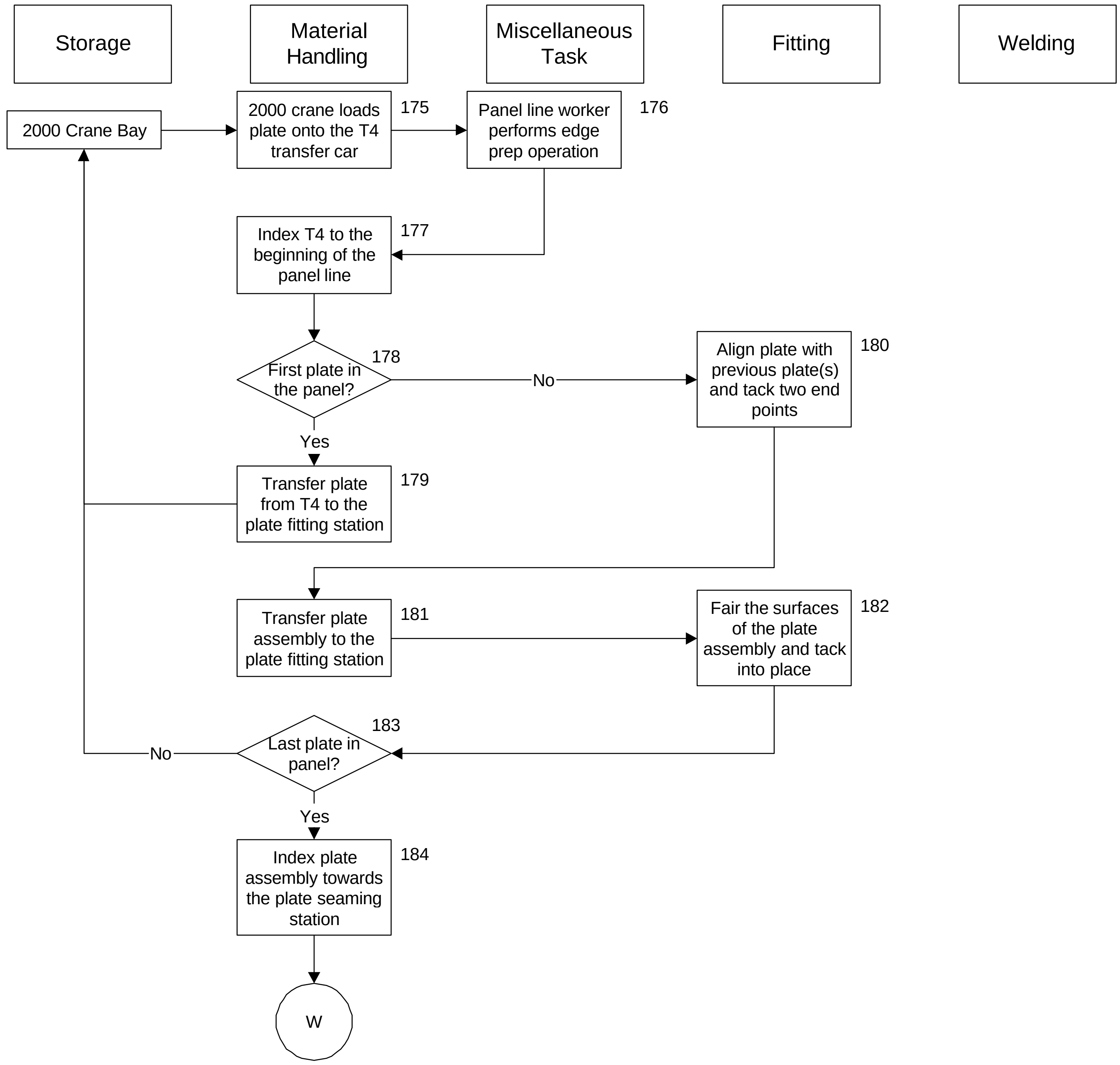
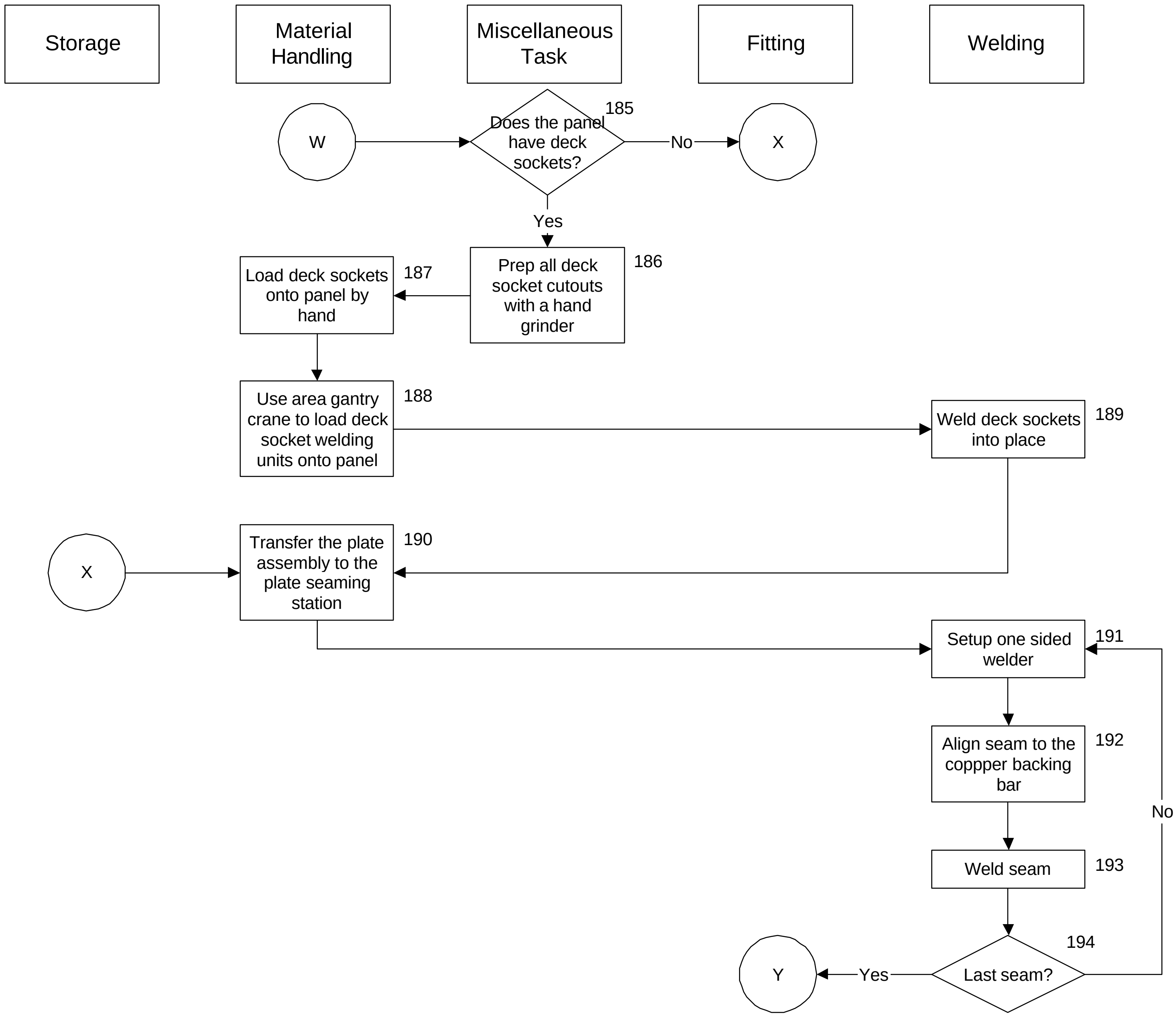


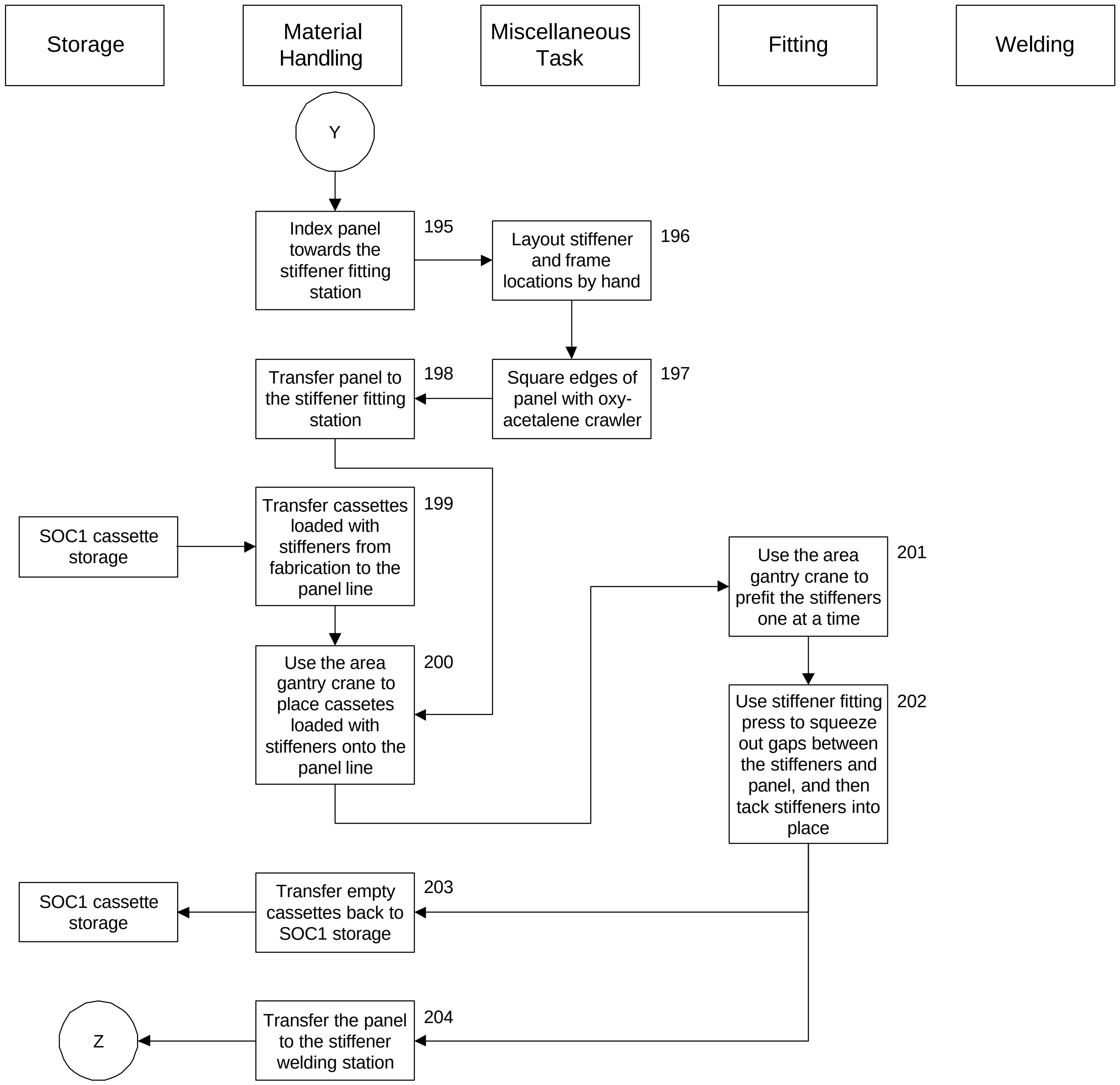
NASSCO Panel Line - 'As-Is' Process Flowchart



NASSCO Panel Line - 'As-Is' Process Flowchart



NASSCO Panel Line - 'As-Is' Process Flowchart



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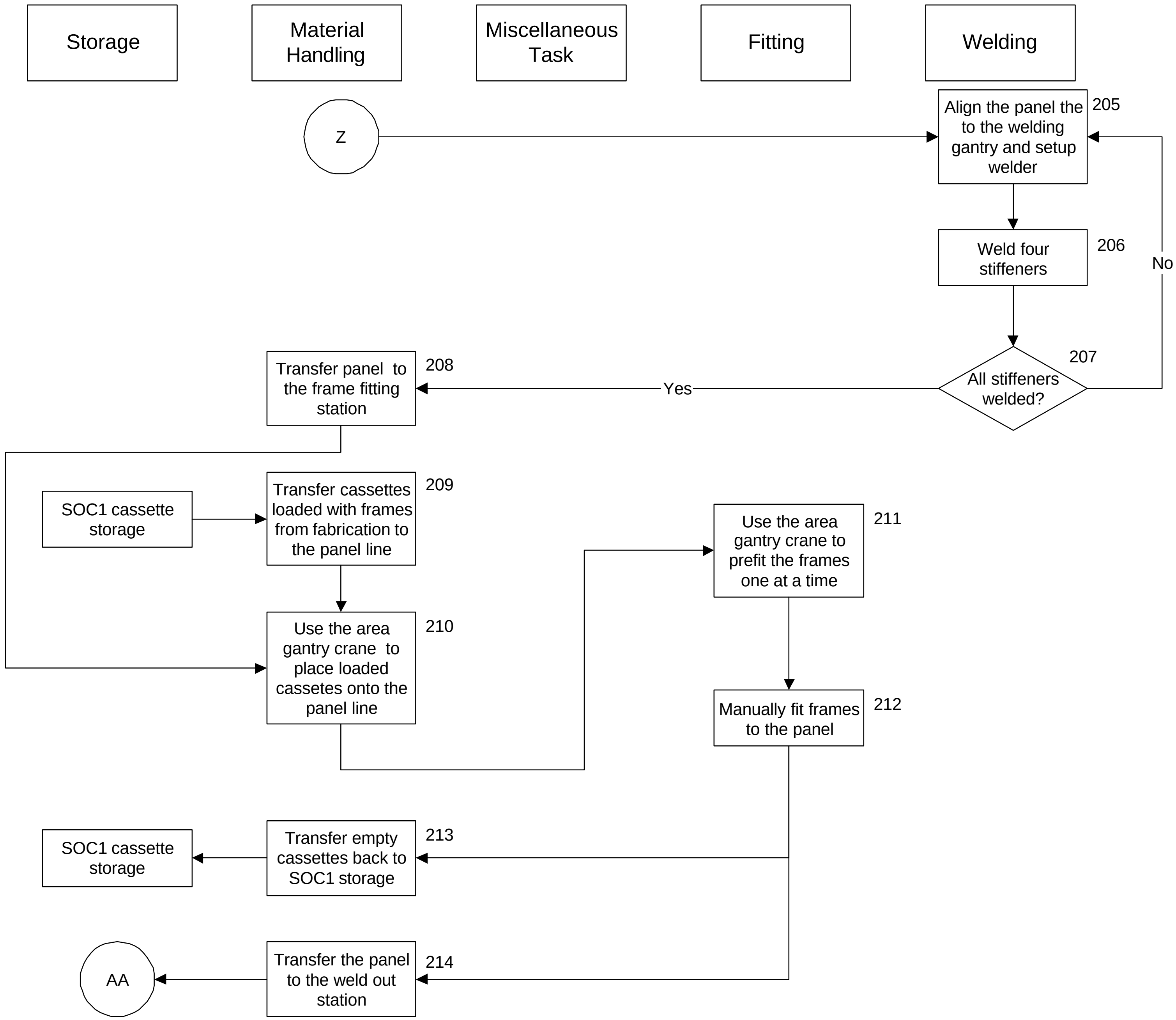

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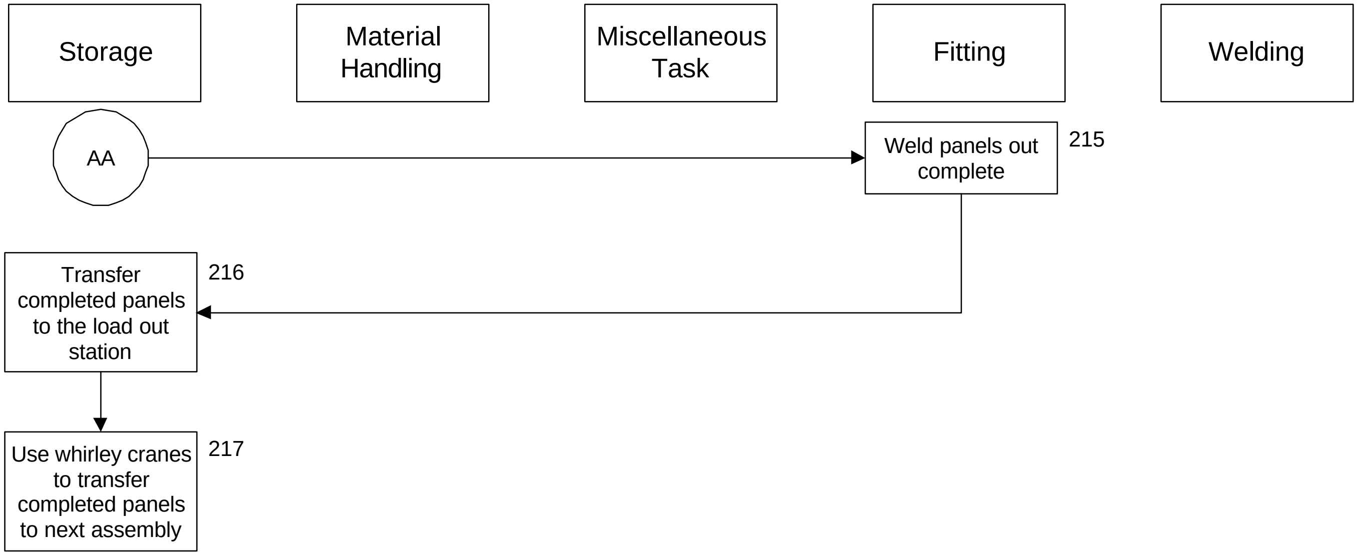

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