APPLYING SIMULATION TO INTERATIVE MANUFACTURING CELL DESIGN

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ABSTRACT

Launching a manufacturing cell to be efficient and lean, yet profitable, is a time-consuming process and is often based on many assumptions. The utilization of simulation models to help design the cell and the logistical structure to support it can expedite and streamline the development process. Assumptions and designs can be validated to help insure effective operations as soon as possible. We have developed a generic simulation model and associated capacity analysis, schedule planning, and target inventory setting software to support the computer based assessment of the operation of cells typical to the plastic manufacturing industry before capital investments are finalized. Model input describes a particular cell, the products it produces, and customer demand for these products. Results show the customer service level, product inventory levels, equipment utilization, and the daily production schedule. Spreadsheet software supports data entry and report examination. All software is integrated in a single simulation environment.

1 INTRODUCTION

The development of a manufacturing cell (Irani, Subramanian, and Allam 1999; Taj et al 1998) to support the launch of a new set of products requires understanding the effect of many different variables as well as their interactions on cell operations. Thus, piloting such a complex system using computer simulation is essential for protecting a safe and effective launch.

We have developed and integrated into a single simulation environment (Standridge 1999) a suite of software that provides for a complete evaluation of a complex manufacturing cell of the type typically found in the plastics manufacturing industry. A generic simulation model of such a cell is the core component of the software suite. The evaluation is done before the time that production needs to be at required levels and to help assure that these production levels are attained in the shortest possible time.

The cell design engineer can provide the same input data to all software in the suite, including the generic simulation model, as well as examine simulation and other results. The engineer can also create various test environments for the cell: change in cycle times, increased variance in demand, decreased efficiency, and so forth to determine how key cell performance measures are affected. Based in part on the results, engineers can deploy their plans with confidence.

This paper discusses the software suite in general, with particular emphasis on the simulation model. The first application of this approach to support the design of a new plastic parts manufacturing cell and test the effectiveness of the software suite is described.

2 SOFTWARE SUITE OVERVIEW

Requirements for the suite of software were based in part on the variables thought to affect cell operations including:

1. Product mix
2. Product volume
3. Product route through the stations
4. Station capacity
5. Scheduled and random machine downtimes
6. Target finished goods inventory
7. Work-in-process (WIP) inventory storage racks
8. Station scrap and inefficiency
9. Required customer service level

Along with the generic simulation model, the software suite includes capabilities for helping to set the values of model input variables from data gathered about the cell. Each cell can produce multiple products. It is not uncommon that all products are not produced on all days due to relatively low volumes as well as significant tooling setup and color changeover times.

A spreadsheet helps guide the cell design engineer in assigning the production of each product to specific days of the week with the goal of balancing the work load on the

bottleneck station. The expected daily demand and bottleneck station throughput rate are multiplied to compute the work hours needed to meet the demand for a single day. The number of days demand to meet (0, 1, 2, 3, 4 or 5) is assigned to each of the five working days of the week. The sum total of the assignments must equal five days.

Product demand data can consist of actual daily shipment data in the form of a discrete distribution for the case of the redesign of an existing cell. In the case of a new cell, the average, minimum, and maximum daily shipment quantities can be obtained in a reasonable way. These quantities are used to determine the parameters of a triangular distribution. It is assume that each product can be shipped to the customer daily and that each product is produced at least once per week.

A program in the software suite generates the percentage points of the cumulative one, two, three, four, and five day product demand distributions from either form of the one day demand distribution. In this way, the target inventory for each product can be set from the distribution corresponding to the maximum number of days between production and to correspond to the management defined customer service level. This is done simply by selecting the percentage point of the distribution that corresponds to the customer service level.

A capacity analysis program computes the expected utilization of each station including the percent busy time, percent idle time, percent down time, percent of time in setup, and the percent of time in color change. These computations are based on the input data discussed above. Note that the results of the capacity analysis can be compared to the utilization results obtained from the simulation for verification and validation purposes (Standridge 2004, Sargent 2001) as well as to gain insight into the dynamic operation of the cell that may not be adequately captured by a simple expected value computation.

All information necessary to describe the cell including: stations, products, product routes, processing times, and customer demand for products is included in a single Excel workbook with multiple spreadsheet.

The report-writing portion of the simulation model provides the following simulation results:

1. Customer service level for each product
2. Customer service level for all products together
3. Station utilization
4. Finished goods inventory levels for each product
5. WIP inventory levels
6. Production level for each product day by day

The software suite includes a program that summarizes simulation results, including the computation of t-confidence intervals (Law and Kelton 2000). All simulation results, as well as all other results, are stored in an Excel compatible format for viewing.

The simulation environment manages multiple scenarios each defined by the information in one workbook of input data along with the corresponding results from simulation experiments and the other software in the suite.

3 THE SIMULATION MODEL

Originally based on a mixed-product foam line fed by four injection molding presses, the simulation model has evolved over the last two years into a generic form that can accommodate many processes and operating constraints as will be discussed in this section.

Information going into the model is organized in tabular format into a series of spreadsheets that comprise one Excel workbook. The spreadsheets and their contents are as follows:

1. Process Flow – Provides an area for the user to graphically display how the processing of product families, each consisting of one or more products, is organized among a set of workstations.
2. Family & Product Information – Production program name, family name, product name, average daily customer demand volume, production schedule day by day, target inventory, and processing batch size are defined for each product in each product family.
3. Family & Routing – For each product family, a routing is defined by listing stations (in order) along with the respective exiting pack densities as shown in Table 1.
4. Release Data – For each product, actual shipping (release) information is given. If release data is unknown, the parameters values for a triangular distribution modeling shipping quantities: maximum, minimum, and average volumes are given.
5. Resource Planning – This sheet includes the nominal time for each operation plus adjustments based on scrap and inefficiency. Thus, the operation time per successfully completed part can be computed.
6. Virtual Schedule – This sheet allows the user to determine which products should be produced on each day by leveling the workload on bottleneck machines as was previously discussed.
7. Station Cycle Information – Information related to scheduled and random downtimes for each station are entered here.
8. WIP Rack Information – The amount of WIP in the system can be controlled by limiting the number of storage racks that hold partially completed parts. For each product, the station where a WIP rack is picked up and the station where a WIP rack is dropped off are specified. The number of parts per rack is the pack density of the product.

Table 1: Example Family and Routing Spreadsheet.

Family & Routing

Family	Op 1	Exiting Pack Density	Op 2	Exiting Pack Density	Op 3	Exiting Pack Density
Front Armrest Substrates	950 Ton Injection	320	None	0	None	0
Front Armrest RH Vinyl	500 Ton Injection	120	Foam Line	120	Window Switch Assembly	120
Front Armrest LH Vinyl	500 Ton Injection	120	Foam Line	120	Window Switch Assembly	120
Rear Armrest Substrates	950 Ton Injection	320	None	0	None	0
Rear Armrest RH Vinyl	500 Ton Injection	120	Foam Line	120	Window Switch Assembly	120
Rear Armrest LH Vinyl	500 Ton Injection	120	Foam Line	120	Window Switch Assembly	120
Front Armrest Foam Retainer	300 Ton Injection	720	None	0	None	0
Rear Armrest Foam Retainer	300 Ton Injection	720	None	0	None	0

A sample Family & Routing spreadsheet is given in Table 1.   A family is comprised of one or more products. All products in a family follow the same production route The routing for each family can be read from left to right across the chart. Note that in plastic manufacturing cells, routes are typically short: 1, 2, or 3 stations.

Front armrests, for example, move from the 500 Ton presses to a foam line to a window switch assembly station before moving to finished goods inventory. The exiting pack densities indicate that the products are stored as WIP between each operation or when awaiting movement to final inventory. A pack density of 1 implies that the product moves according to one-piece flow (Sekine 1992). A cell name of "None" means that the end of the route has been reached.

The model is implemented using the process world view in AutoMod Student Version 11 (Banks 2004). The model is comprised of a set of processes. Each of these is discussed in turn.

At the beginning of each simulation replicate all the data from the spreadsheet is read and processed for use in the model. For each station downtime specified, a cycle of operating to failure and then down until repaired is initiated. After repair, the station operates until the next failure.

At the end of each replicate, summary statistics concerning simulation performance measures are written to spreadsheet compatible files. In addition, the number of units of each product scheduled for production is recorded daily in such a file.

There is a process that represents the start of each day. It is highly likely that the number of units produced of a product will not exactly equal the pack density specified following the last station on the route. These partially filled part containers are moved to finished goods inventory at the start of each day.

Next, demand of each product is determined as a random sample from the daily demand distribution function and scheduled for shipment from inventory. If a complete shipment can be made, the service level for that day for that product is 100% , else it is zero.

Finally production is scheduled for each product. A product will be produced if it is scheduled for production on that day of the week and if the finished good inventory plus the amount currently in production is below the target inventory level for that product. The production quantity is the smallest multiple of the user-defined processing batch size for that product that will bring the finished goods inventory level to or above the target.

Note that this will likely result in the finished good inventory exceeding the target inventory. Thus, inventory levels will tend to exceed those originally planned and the customer service level may exceed management targets. Additional experiments can be conducted to test the effects of lower target inventory levels on the customer service level.

Further note that the production quantity for each product is a random variable that is related to the random variable modeling daily customer demand. Thus there is some probability that on any given day, production capacity is less than the scheduled production. This may result in incomplete shipments on subsequent days.

The production scheduling process sends in an entity representing a number of parts equal to the production batch size to the routing process. Thus, more than one entity per product may be sent to the routing process each day.

The routing process selects the next, which could be the first, station to which to send the entity and routes the entity to the single, generic station process. If an entity needs a WIP rack before proceeding to a station, it acquires the WIP rack in the scheduling process. If the entity is at

the end of its route, it is sent to the add to inventory procedure, which increases the number of parts in the finished goods inventory.

The station process includes the logic for setup due to tooling changeovers, setup due to color changes, station processing, WIP rack drop-off and pick-up, as well as creating batches of WIP of size equal to the exiting pack density for that product as specified by input data. Full batches are sent to the routing process for further processing.

Setup for tooling changeovers occurs whenever the product to be processed next at the station belongs to a different family than the product last processed. Setup for color changes occurs whenever the product to process next at the station is of a different color than the product last processed. The number of parts processed concurrently depends on the tooling used on the machine at the station or on the number of workers at a manual operation station.

A WIP rack is dropped off (made to enter the idle state) if the station is the drop off station and all the parts on the rack have started the operation at the station.

Upon completion of the operation, the parts are placed in the WIP inventory for that product at the station. Whenever the WIP inventory exceeds the exit packing density specified in the input data, as many entities as possible, each representing a number of parts equal to the exit packing density, are sent to the routing process.

Table 2 summarizes the main processes in the model.

4   APPLICATION

The entire software suite, and particularly the simulation model, was used to help launch the Summit program at Leon Plastics. The Summit program consisted of eight different product families with varying design configurations and routings. Some parts were instrument panel components while other parts were console lids for center consoles. The implementation of the model helped ensure balanced station loading and appropriate inventory levels. It also allowed the program team to investigate different processing scenarios including moving some operations in-line with other operations.

Program operations were based on an in-line vacuum-forming process. Leon has done vacuum-forming for many years, but these products presented new challenges. There were two different materials specified for the program – a foamed-back vinyl material for the console lids, and a TPE/TPO material for the IP components. Along with the different materials, the quality expectations for the edge wrapping required unusual processing methods and unique tooling.

This work is spread out over three vacuum-forming machines. The work was delegated first based upon the part configurations and then on machine loading. Similar parts that require similar manning were kept together as

Table 2: Model Processes Summary

Process	Primary Function	Entity sent to
Start of Replicate	Read input data Start station breakdown and repair cycles	
End of Replicate	Write reports	
Start of Day	Place partially filled containers from previous day in inventory Determine daily customer demand, remove from inventory, record daily service level Determine demand and schedule production and report production volume	Route
Route	Another station on the route, End of route reached	Station Add to FGI.
Station	Setup for family and color changes Station operation on parts Release WIP rack if required Add to WIP inventory Forward full containers, acquiring WIP rack if needed	Route
Add to FGI	Add parts to product finished goods inventory	

much as possible. The vacuum-formers are known to be the bottleneck for this system. Even though some of the downstream manual operations were slower than the vacuum-forming process, more man-power could be applied to those to increase the throughput rate. Thus, the team's main objective was to ensure that the vacuum-formers were never constrained.

The routings for each product family are shown in Figure 1 and were detailed in the input spreadsheets. Products that share facilities are shown.

Daily production volumes were based on customer requirements. The team was not anticipating any great fluctuation in demand as their final customer builds vehicles based on the Toyota system of production. A limited amount of vehicles are required to be built each week after which the line is shut down.

Since the demand does remain relatively stable, the model can be used to test other manufacturing scenarios if desired. One such scenario might be testing if Leon can meet demand requirements if only three out of four of the cavities in a tool are capable. Another scenario might be monitoring customer service level with a smaller target finished goods inventory.
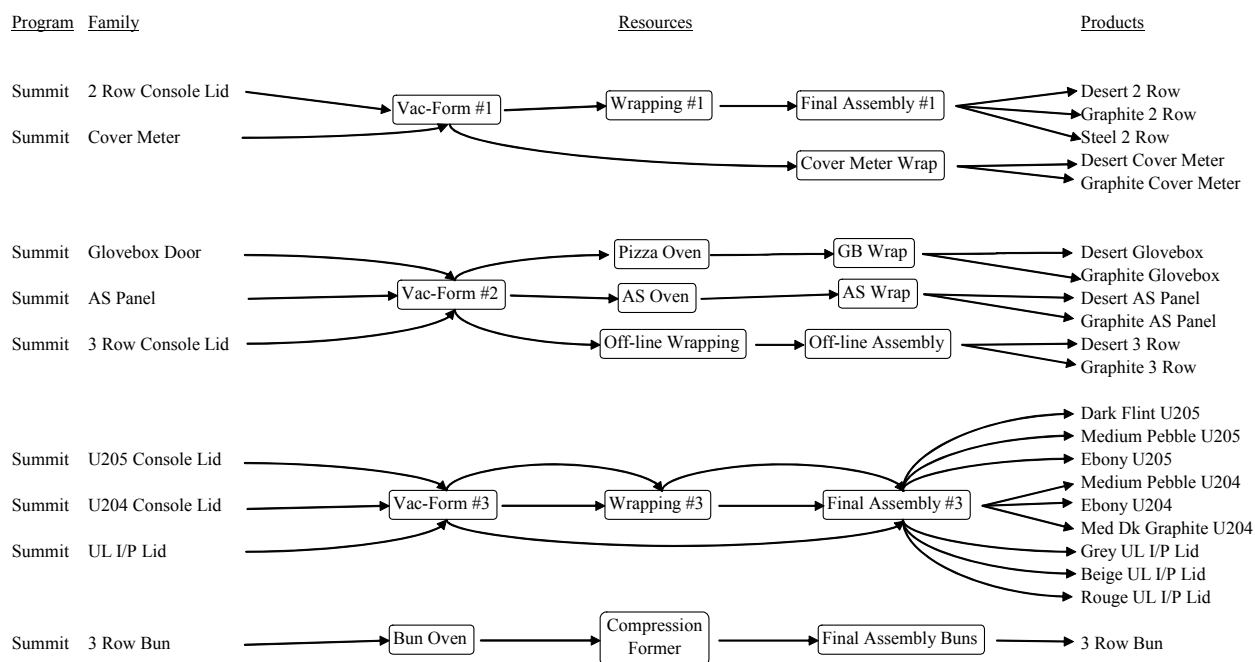
Process Flow

Figure 1: Routings for Summit Product Families

Setup time and resource cycles are based on actual data. Changing over from one family to another requires forty-five minutes of down-time for tooling changes and process parameter changes. Efforts are being made to decrease this changeover time, though it will never be zero.

The station cycles represent scheduled preventative maintenance on equipment and unscheduled down-times due to processing issues. Scheduled preventive maintenance happens once a month for three contiguous shifts. Set-up calls happen randomly and last approximately fifteen minutes.

Target inventory levels were based on customer demand distributions and the desired customer service level of 99%. Product shipments to the customer are required daily, five days per week. Lacking historical data concerning shipments, demand for each of the 21 products was modeled using a triangular distribution with the mean equal to the expected demand stated by the customer. The customer projected little variation in demand so the minimum was set at 80% of the mean and the maximum was set at 120% of the mean.

To avoid excessive setups, which take about 45 minutes, many products are produced only on selected days of the week. Thus, there must be sufficient inventory on hand to cover shipments on the days of no production. Thus, the two-day, three-day, four-day, and five-day distributions of demand were generated numerically by a program in the suite with the parameters of the triangular distribution modeling the one day demand as input.

For each product, the largest number of days between production is identified. If a product is scheduled to run every day (e.g. 3 Row Bun), then the number of days is 1, and the target inventory only needs to protect 99% of one day's demand, 786 pieces. If another product is scheduled with a maximum three day gap between runs, such as Graphite AS Panels, the target inventory quantity will be found in the three-day distribution at the 97%-point, 924 pieces. The 97% point can be used since inventory should be sufficient for a 100% service level on the first and second days. A 97% service level on the third day yields an average service level of 99%.

5   RESULTS AND DISCUSSION

The simulation model as well as the other software in the suite were used to help in the design and implementation of the Summit production program whose products, stations and routes are shown in Figure 1 above. The capacity analysis portion of the software suite solves for the percent busy time, down time, tool change over time, color change over time, and idle time of each station based on projected production volume, facility standard production rates, and available hours.

Simulation results for the Summit project were obtained by running the model for 10 replicates of one year run length. A year of production consists of 240 days. Key outputs for the model include customer service level for the entire line and for each individual product, station

utilization, finished good and WIP inventory levels, and production levels for each product by day. Simulation results from each of the 10 replicates of the simulation are input to a summary program in the software suite that computes summary statistics and t-confidence intervals as well as producing a single file containing all results.

Based on these simulation results, the estimated percent busy time can be compared against the same value computed by the capacity analysis program for verification and validation purposes as shown in Table 3.

Table 3: Comparison of Percent Busy Time Results

Station	Capacity Analysis (Busy %)	Simulation Results (Busy %)	Difference Capacity - Simulation
Vac-Form #1	60.33	60.22	0.11
Wrapping #1	31.23	31.03	0.20
Final Assembly #1	42.33	42.06	0.27
Cover Meter Wrap	58.20	57.84	0.36
Vac-Form #2	53.67	53.89	-0.22
Pizza Oven	24.65	24.46	0.19
GB Wrap	24.65	24.46	0.19
AS Oven	30.81	30.63	0.18
AS Wrap	30.81	30.63	0.18
Off-line Wrapping	19.05	18.84	0.21
Off-line Assembly	19.05	18.84	0.21
Vac-Form #3	88.86	88.87	-0.01
Wrapping #3	57.90	57.72	0.18
Final Assembly #3	88.86	88.45	0.41
Bun Oven	59.79	59.63	0.16
Compression Former	59.79	59.63	0.16
Final Assembly Buns	59.79	59.63	0.16

Note that the difference between the percent busy times computed by the capacity analysis program and estimated from 10 replicates of the simulation model are small and operationally insignificant, less than 0.5% for all stations. This was taken to be strong validation and verification evidence.

It was mentioned previously that the vacuum-forming machines were known to be the bottleneck in each respective product routing. This was confirmed by the results in Table 3. The vacuum-forming machines were busy 60.22%, 53.89%, and 88.87% of the time, respectively, for machines 1, 2, and 3, with 99% confidence intervals of 60.06% to 60.38%, 53.77% to 54.02%, and 88.65% to 89.09%.

Some of the lowest utilized stations were the pizza oven (24.46%) and wrapping (24.46%), the AS oven (30.63%) and wrapping (30.63%), and the off-line wrap-

ping (18.84%) and assembly (18.84%) stations. The Summit launch team is trying to find a way to combine both the manning and the work cells of these products so that they are better utilized. It may require some special scheduling, but the utilization results obtained here prove that combining these work cells may be beneficial.

Besides giving a snapshot of how much work a line had, this information is especially valuable in providing insight into the meaning of the other performance measure estimates. For example, suppose in the actual operation of the cell, the lowest customer service levels consistently were for products produced by the station with the highest utilization. It may be that the process was altered for quicker cycle times, thus providing more machine capacity. The line could be sacrificing quality for capacity. Poor customer service level can not be blamed on machine utilization if the model proves that there is ample capacity, but it may provide some clues to where other deficiencies are.

Table 4 provides product inventory and customer service level results from the simulation including approximate 99% t-confidence intervals for the maximum inventory and customer service level as well as the target inventory input to the simulation for each product. All products carried maximum inventory levels larger than the target inventories. That is due to the way that the products run in discrete batch quantities.

The average customer service level for the entire line was 97.68% with an approximate 99% t-confidence interval of 97.47% to 97.90%. Thus, there is a statistically significant difference between the target service level of 99% and the simulation results. This difference was due to primarily to production delays resulting from the high utilization of vacuum–former #3 as well as long scheduled downtimes of the three vacuum-former stations for maintenance. The model did not include inventory build up procedures in anticipation of these downtimes.

The difference is reflected in the individual products as well. The 99% approximate t-confidence intervals covered the target service level of 99% for 12 of the 21 products. The service levels for the other 9 products came in below the target customer service level.

The service level deficiencies are well spread out over products that use each of the three vacuum forming machines. No one machine is creating more of a service issue than the other.

The 3 Row Bun product, which does not share resources with any other product, had a greater than desired average customer service level of 99.83%. Upper- and lower-bound confidence intervals were 99.61% to 100.05%. The lowest performing product was the medium pebble U205 lid with an average service level of 91.63% and an approximate 99% t-confidence interval of 90.36% to 92.89%. The greatest performing product was the U204 console lid in medium dark graphite with 100% average customer service level.

Table 4: Simulation Results Concerning Product Inventories and Service Levels

	Maximum Inventory (pcs.)	99% CI Lower Bound	99% CI Upper Bound	Target Inventory (pcs.)	Customer Service Level (%)	99% CI Lower Bound	99% CI Upper Bound
Desert 2 Row	809.50	808.20	810.80	650.00	99.25	98.98	99.52
Graphite 2 Row	1302.10	1300.46	1303.74	1143.00	99.04	98.83	99.25
Steel 2 Row	962.40	957.90	966.90	804.00	96.75	95.74	97.76
Desert Cover Meter	532.60	531.73	533.47	499.00	98.33	97.98	98.68
Graphite Cover Meter	945.10	939.06	951.14	924.00	94.96	94.02	95.89
Desert Glovebox	635.80	632.90	638.70	499.00	99.29	98.94	99.64
Graphite Glovebox	1061.20	1059.54	1062.86	924.00	99.13	98.88	99.37
Desert AS Panel	627.00	626.16	627.84	499.00	99.75	99.53	99.97
Graphite AS Panel	1047.10	1040.52	1053.68	924.00	98.92	98.70	99.14
Desert 3 Row	588.30	579.76	596.84	446.00	95.63	93.98	97.27
Graphite 3 Row	973.70	957.79	989.61	834.00	95.38	94.56	96.19
Dark Flint U205	1906.60	1905.73	1907.47	1764.00	97.33	96.97	97.69
Medium Pebble U205	1107.60	1105.59	1109.61	966.00	91.63	90.36	92.89
Ebony U205	744.50	743.77	745.23	602.00	94.79	93.82	95.76
Medium Pebble U204	591.60	589.84	593.36	450.00	99.29	98.84	99.75
Ebony U204	484.00	482.32	485.68	342.00	99.12	98.61	99.64
Med Dk Graphite U204	167.40	166.53	168.27	25.00	100.00	100.00	100.00
Grey UL I/P Lid	530.40	529.53	531.27	428.00	95.08	94.36	95.81
Beige UL I/P Lid	569.40	565.37	573.43	471.00	98.96	98.66	99.26
Rouge UL I/P Lid	146.40	143.97	148.83	56.00	98.92	98.24	99.59
3 Row Bun	947.00	947.00	947.00	786.00	99.83	99.61	100.05
Overall					97.68	97.47	97.90

The medium pebble U205 lid is the second highest volume job with a daily average take-rate of 435 pieces. The medium dark graphite U204 lid is the lowest volume job with only 8 pieces of daily demand. Both of these items are produced on vacuum former #3, which was shown in Table 3 to be the bottleneck station. Because the U204 lid is such low volume, however, the inventory is easier to build. The batch quantity size of 144 pieces far exceeds the demand of 8 pieces per day. The poorer performance of the medium pebble U205 lid is likely a result of the capacity constraints on vacuum former #3 resulting in a lack of sufficient inventory. Another simulation scenario could test higher target inventories to see if that improves performance.

Table 5 shows a representative daily production schedule generated by the simulation including: day of the year, day of the week, pieces of product queued to run, the inventory position of the product (finished good inventory + WIP pieces), and the target inventory. The results shown table 5 are useful in allowing production schedulers and inventory managers to justify how they are managing pro-

duction. It shows what was run and the relationship between the product inventory and the target.

Control of WIP inventory is also a priority. There are only three Summit products that move internally in WIP containers: the gloveboxes, the AS Panels, and the 3 Row console lids. As long as the quantity of WIP containers is unconstrained, the service levels for each of these products will not be affected. The ideal solution is to have just enough WIP containers in the system to not compromise customer service levels. Table 6 provides maximum WIP rack quantities and their approximate 99% t-confidence intervals. The maximum number of WIP containers used accurately reflect the number of containers used in the Summit work cell and is an estimate for the smallest amount of containers needed.

After seeing the results of the first simulation case, a second case; moving one of the product families from vacuum-former #3 to vacuum-former #2, was designed. The purpose of this second design was to see how the capacity constraints on vacuum-former #3 affected the average service levels. The UL I/P family of products was moved

Table 5: Sample Daily Production Schedule from the Simulation

Day	Day of Week	Product	Pieces	Inventory	Inv. Position	Inv. Target
1	1	Desert 2 Row	324	438	762	650
1	1	Graphite 2 Row	486	736	1222	1143
1	1	Steel 2 Row	324	546	870	804
1	1	Desert Glovebox	280	342	622	499
1	1	Graphite Glovebox	420	621	1041	924
1	1	Desert AS Panel	260	357	617	499
1	1	Graphite AS Panel	390	620	1010	924
1	1	Dark Flint U205	864	1026	1890	1764
1	1	Medium Pebble U205	432	534	966	966
1	1	Ebony U205	432	299	731	602
1	1	3 Row Bun	810	18	828	786
2	2	Desert Cover Meter	324	202	526	499
2	2	Graphite Cover Meter	540	394	934	924
2	2	Desert 3 Row	324	250	574	446
2	2	Graphite 3 Row	486	417	903	834
2	2	Ebony U205	288	419	707	602
2	2	Medium Pebble U204	288	164	452	450
2	2	Ebony U204	288	146	434	342
2	2	Med Dk Graphite U204	144	8	152	25
2	2	Grey UL I/P Lid	416	50	466	428
2	2	Beige UL I/P Lid	312	201	513	471
2	2	3 Row Bun	648	258	906	786

Table 6: WIP Rack Requirements

	Maximum	99% CI	99% CI
	WIP	Lower	Upper
	Racks	Bound	Bound
Glovebox Rack	4.80	4.37	5.23
AS Panel Rack	5.00	5.00	5.00
3 Row Console Lid Rack	4.00	4.00	4.00

from the third vacuum former to the second. The UL I/P lids do not follow the same product flows as the U205 lids and the U204 lids, the other two product families on vacuum-former #3. At vacuum former #2, there is adequate room in the cell to complete the processing of UL I/P lids in-line to the vacuum former, so their process flow does not have to change.

The results of simulating the second case showed that the resource constraint moved from vacuum-former #3 to vacuum-former #2, as was expected. Moving the UL I/P work content from one machine to another resulted in three general improvements. The machine loading was slightly more level across the three vacuum-formers. Utilizations on vacuum-formers 1, 2, and 3 in case #1 were 60.22%, 53.89%, and 88.87%, respectively. Case #2 had utilizations of 60.22%, 85.04%, and 57.37%, respectively. The overall service level also improved in case #2 from an average of 97.68% to an average of 98.12%, with an approximate 99% t-confidence interval of 97.85% to 98.38%. This difference is statistically significant since the approximate 99% t-confidence interval for the difference in the overall service level between the two cases is 0.29% to 0.58% with an average difference of 0.43%.

The poorest performing product was a 3 Row lid, while two other products (medium dark graphite U204 lid and 3 Row bun) achieved 100% customer service levels. The average total amount of inventory carried between case #1 and case #2, case #2 had approximately 2500 more pieces of inventory than case #1 (19,184 pieces versus 16,679 pieces).

The more level loading of the three vacuum-forming machines doesn't make a compelling argument for adopting Case #2 as the better way to manufacture the Summit products. The increased level of inventory does not support that decision either, unless management decides that the improved service level out-weighs those other two factors.

6   SUMMARY

The use of lean methods for manufacturing have lead, in part, to the decline of the use of simulation in this application area (Harit 2005). However, the application of simulation in lean driven manufacturing operations still has much potential.

The application of simulation to aid in the design and implementation of a plastics product manufacturing cell has been discussed. A generic, data driven simulation model is complemented by other software that analyzes capacity, generates customer demand distributions for products, and summarizes simulation results. All software in the suite has been integrated into one simulation environment.

Simulation and other analysis results were used to assess cell performance with respect to customer service levels versus the management specified target, inventory levels versus predetermined target levels, and station utilization. Alternative assignment of product families to workstations were compared.

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