Visteon's Sterling Plant Uses Simulation-Based Decision Support in Training, Operations, and Planning

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Visteon's Sterling plant uses a strategic decision support system (DSS) that integrates plant-floor information systems and simulation for three related, mutually reinforcing purposes: productivity training, productivity improvement in operations, and design of new operations. A self-directed team of the front-axle production line at the plant used the DSS to increase production of front axles for Ford Expeditions, Lincoln Navigators, and F-series trucks. Improving the productivity of this production line was important to the plant, the customers, and company profitability as the US market for high-profit margin 4 × 4 trucks and sport utility vehicles exploded. As a result of the new system, productivity improved by more than 30 percent. The plant produced an "extra" 144,496 front axles between January 1997 and July 1998. The DSS was also instrumental in Visteon avoiding a $10 million modification on the line that would have been inefficient. Visteon used the DSS in designing a new line with higher productivity and $5.5 million cost savings.

Visteon Automotive Systems, until 1997 Ford Automotive Products Operations, is the world's second largest supplier of automotive parts and components. The automotive-supplier industry is a quarter-trillion-dollar-a-year market. An

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enterprise of Ford Motor Company, Visteon has 82,000 employees and 120 manufacturing, engineering, sales, and technical centers located in 21 countries. Visteon has four divisions: Automotive Components; Electrical and Fuel Handling; Chassis; and Glass.

> If you work on improving productivity on any operation other than the bottleneck, the only result is frustration.

The chassis division manufactures axles and driveline, steering, and chassis components in several plants in the US and overseas. The Sterling plant produces driveshafts and axle assemblies for cars and trucks. The plant was built in 1956 by the Ford Motor Company. It is the world's largest gear-driveshaft- and axle-manufacturing plant. It employs over 4,000 people and contains more than 2.8 million square feet on 156 acres of land in Sterling Heights, Michigan. The Sterling plant is the only Visteon plant in North America that makes driveshafts and axle assemblies, shipping its products to 20 automotive plants in North America, Argentina, Venezuela, and England.

The Sterling plant formerly produced rear axles only, but in 1996, it launched a new production line to manufacture front axles for four-wheel-drive (4 × 4) trucks and sport utility vehicles (Ford Expeditions, Lincoln Navigators, and F150 and F250 trucks). The demand for front-axles was overwhelming, and within the first year, demand for axles for 4 × 4 trucks and SUVs increased to 550,000 units, well beyond our planned production capacity of 400,000 units. Every axle short of the demand was a lost sale of a highly profitable 4 × 4 F-series truck, Ford Expedition, or Lincoln Navigator. It became extremely critical to increase the productivity of the front-axle line while studies were being carried out to investigate whether to expand the existing line or add a new line.

Front Axle Production Line at Visteon Sterling Plant

The plant assembles front axles on a closed-loop production line with 39 stations served by an asynchronous conveyor (Figure 1). A fixed number of pallets circulate. Machined component parts and purchased part kits enter the system at a loading station where they are manually loaded onto pallets. The pallets, each containing the parts needed for an axle, progress through other stations at which operations are performed. Once all the operations have been performed, the pallet goes to the unloading station, where the fully assembled axle is manually unloaded from the pallet. The finished axle assembly leaves the system while the empty pallet goes to the loading station to receive a new part. A radio frequency (RF) record-read tag on each pallet indicates what operations have been performed on the associated part. When a pallet enters a station, the information from the RF-tag is retrieved, an operation is performed on the part, and the RF-tag is updated. If the tag shows that the part has been rejected or that the pallet is empty, the pallet is immediately released with no operation. Pallets that hold rejected parts are automatically diverted into repair bays. The line is very complex since most of its stations are automatic and there are no buffers except

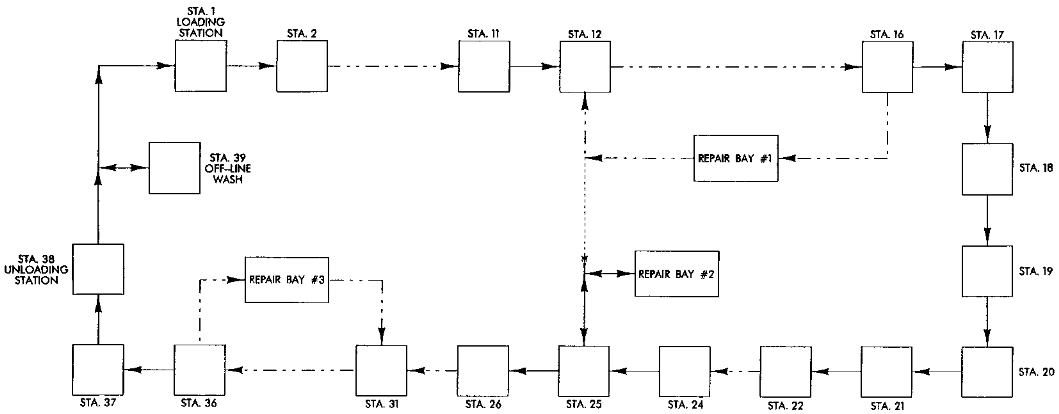


Figure 1: In front-axle production, a closed-loop production line uses an asynchronous conveyor. At Station 1 (the loading station), parts and kits are loaded onto pallets. Pallets progress through subsequent stations to reach the unloading station, where the fully assembled axles are unloaded from the pallets. The finished axle assemblies leave the system while the empty pallets are moved to the loading station to receive new parts.

for a few pallets moving on the conveyor between stations. When one station goes down, it creates a domino effect on other stations in the line, and the line soon stops.

All production data are available from the machine-monitoring system (MMS), a plant-floor system that collects, stores, and reports machine productivity information. The machine controls provide the information, which is pooled for the MMS through communication lines. The data is collected in real time and stored in a database for later retrieval. The information collected includes machine auto time, downtime, starved time, and blocked time along with the times of and the number of their occurrences. The MMS reports also display machine cycle time (in seconds), machine faults, build counts, number of good parts, rejected parts, productive time, effective cycle time, and percentage of rejects. With MMS, plant employees can concentrate resources on improving productivity rather than on collecting data. The MMS gives the operators the information they need to identify and prioritize problems and opportunities and to implement improvements. This results in improved focus, better solutions, and improved operations. The front-axle production line was the first application of MMS at the Sterling plant.

The front-axle department was also the first area of the plant to apply the Ford production system (FPS). The FPS is a lean, flexible, and disciplined common production system that is defined by a set of principles and processes, and that employs groups of capable and empowered people who are learning and working safely together to produce and deliver products that consistently exceed customers' expectations in quality, cost, and time. The major elements of FPS that the plant applied to the department were visual factory (the use of standardized controls that enable individuals to immediately recognize the standard and any deviation from it, and that create a visual language that helps them to distinguish quickly between normal and abnormal and makes waste obvious), error proofing (a process-improvement system to prevent a specific defect from occurring), industrial materials (non-production-related materials required to operate a plant with the right part, at the right place, at the right time, at the right cost), quick changeover (team-based improvements to reduce setup and changeover time), Ford total productive maintenance (small groups working to continuously improve the overall effectiveness of their equipment and processes), quality process sheets (a method work groups use to document standards for performing their tasks to aid continuous improvement through the elimination of waste), and the FPS measurables. The FPS measurables are dock-to-dock time (the elapsed time between the unloading of raw material and the release of finished goods for shipment), first-time-through capability (the percentage of units that complete a process and meet quality guidelines without being scrapped, rerun, returned, or diverted into an off-line repair area), build to schedule (the percentage of units scheduled for a given day that are produced on the correct day and in the correct sequence), and overall equipment effectiveness (a measure of the availability, performance efficiency, and quality rate of a given piece of equipment (constraint operation)).

Using the FPS system, the front-axle department organized the existing hourly workers into a self-directed work group. The workers had volunteered for the front-axle production line with the understanding that they would be working in a self-directed group responsible for tracking its own performance and developing plans for achieving its objectives for safety, quality, cost, and productivity. The work group meets weekly to discuss its performance and to plan actions for improvement (the line is shut down during the meeting).

Ron occasionally had to excuse individuals from meetings when they persisted in expressing their opinions.

First, it was necessary to educate the workers about the importance of improving productivity and of using MMS to do so. Productivity is a measure of how effectively you are using resources to produce various goods and services. You can increase productivity by producing more with the same amount of resources or by producing the same amount with fewer resources.

The MMS was new at the Sterling plant, and employees were reluctant to rely on it. George Pfeil, the plant manager, wanted the employees to focus their efforts on improving operations at bottleneck stations to improve overall productivity. George frequently said that if you work on improving productivity on any operation other than the bottleneck, the only result you'll get is frustration. The ultimate goal was to use information systems to increase productivity by eliminating bottlenecks and improving operations. You can't completely eliminate bottlenecks. You eliminate one, and as the line speeds up in response, you find something else functions as a bottleneck at the new speed. One solution is to use the MMS continuously to monitor bottlenecks. Unfortunately, experienced people tend to rely on observation, guesses, and hunches regarding bottlenecks, instead of using structured analysis and information technologies (IT). William King [1994], in his article "Forecasting productivity: The impact of IT," refers to a classic Hollywood movie *Field of Dreams*. He points out that, first we may need to question the field-of-dreams notion: Build it and they will come. In IT, because a technology can have an identifiable impact on people and organizations does not mean that it will have that impact. George Pfeil, who successfully launched the Romeo engine plant in 1990, has always wanted to overcome the resistance of people in the plant to using IT and structured analysis to improve productivity and solve problems. While at the Romeo plant, he wanted to offer a course in productivity improvement based on computer-based simulation. He realized that trainees could see the fruits of their efforts to improve productivity in a simulated factory immediately, instead of waiting weeks or months in real life. Shahram Taj, a professor at the University of Detroit Mercy, who became a faculty intern at the Romeo Plant, developed a (discrete-event) simulation-based productivity training course called Productivity 201. The main challenge was to develop the course in such a way that information from the simulated factory could be transferred to the MMS, and trainees could then use MMS information to run the simulated factory. By the end of 1993, he had successfully developed and implemented "Productivity 201," and George Pfeil started to teach the course. The training class has been very successful because the realistic simulation resembles actual production while providing information in a familiar format.

Simulation-Based Productivity 201 Training

In the Productivity 201 course, we simulate a hypothetical manufacturing department and use the simulation as a teaching tool. This manufacturing department consists of 16 machines called OP1 to OP16 (Figure 2). The OP1 never starves (unlimited parts are available for the first operation). There are 10 stations in each machine. Each station can process only one part at time. If one station goes down, the machine goes down too. A buffer after each machine can hold few parts. Parts move from one station to the next station in each machine. After a part goes through all the stations in the machine, it moves to the buffer and waits there until it is pulled by the first station of the next machine. Customers pull parts from the line. Each machine has an associated scrap rate (percentage rejects lost to the system). Machines can be in several states: blocked

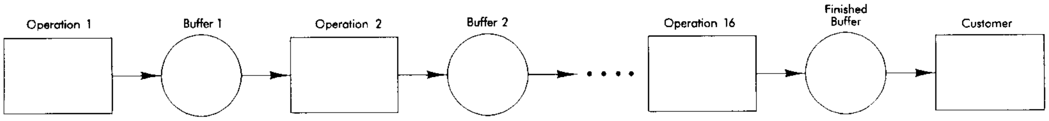


Figure 2: The simulated factory has 16 operations (machines), OP1 to OP16, each consisting of 10 stations. Machines pull parts from buffers and push them from station to station and finally to a dedicated buffer. The customer pulls parts from the last buffer.

(has finished operations but the parts are unable to move on); starved (has insufficient parts to perform its work); down (has broken down); running (is doing productive work); and off-shift (is not scheduled to work). The simulation model is written in Witness, an interactive, visual manufacturing-simulation package.

There are 56 hours available in each week for production runs and preventive maintenance (PM). The department uses the PM hours to increase machine uptime, reduce scrap, and improve cycle time. PM can be scheduled for a maximum of 24 hours (three days). At any given time, either production or maintenance occurs. The weekly PM can be scheduled to fix a maximum of five faults. Regardless of the length of production runs, the customer is always running Mondays through Fridays.

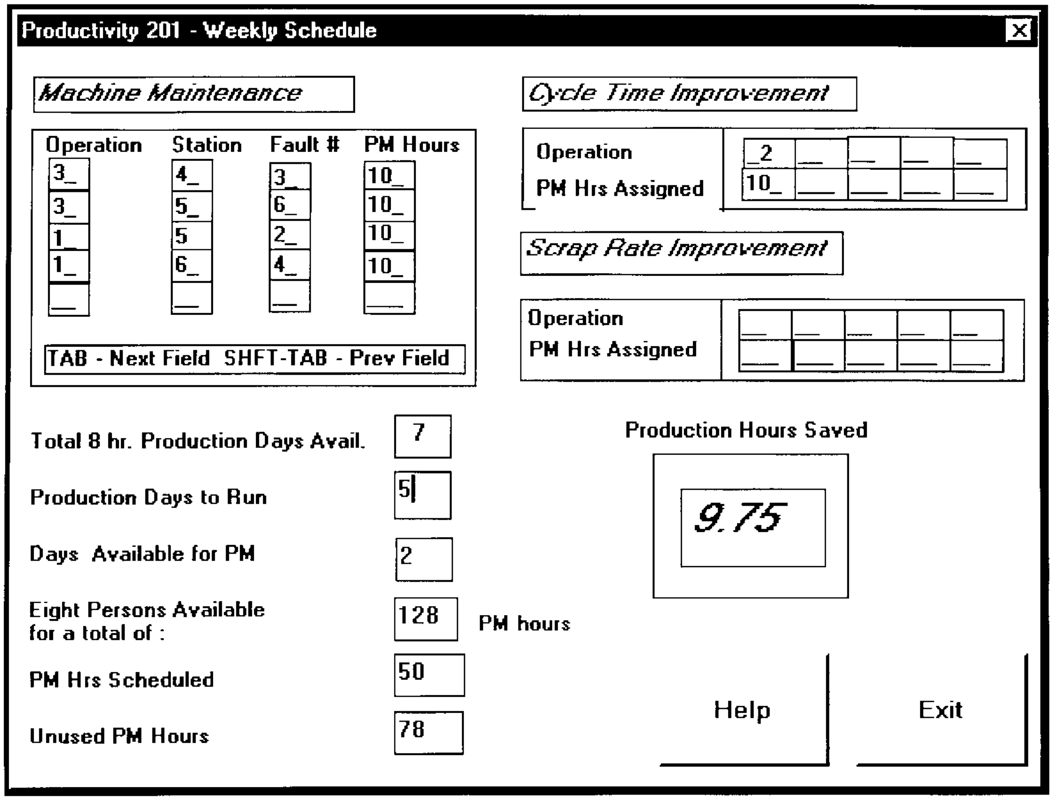
The Productivity 201 class is scheduled for three to four sessions. The trainees are production managers, supervisors, engineers, and production workers. The instructor sets the system's parameters and runs the simulation for several weeks prior to the beginning of the class. The first day of class, the instructor divides the class of trainees into teams and gives them basic information about the simulated production department (line). Teams then interact with the MMS to obtain complete information about production and to devise a plan of action for the following week. They decide on the upcoming week's production and maintenance schedule and allocate PM hours to reduce various bottlenecks. After the teams enter the plan of action into a user-friendly computer interface (Figure 3), the simulated department runs for one week in a few minutes of computer time. Teams then obtain the results from the MMS. The instructor evaluates the teams on meeting customer requirements, department efficiency, and cost.

All the simulated departments have the same status in the beginning but come to differ as the teams follow different plans of action. Teams get updated and detailed production data for their simulated factories from the MMS on their workstations. Their task is to schedule production and PM for the upcoming week and run (simulate) the production. Using an interface screen (Figure 3), the teams enter the number of production days, compute the available hours for PM based on the remaining unused production days and the size of the PM crew, and enter them to improve machine uptime, reduce cycle time, and improve the scrap rate. Teams are limited to five PM improvements per week. The teams schedule production and PM based on their analyses of the production data, downtime, cycle time, and part-build counts from the MMS. The hours saved, which are computed internally, are the number of hours saved for the week (not allocated to production or PM).

After entering all the information, the user clicks the Exit button. This loads the simulated model, which it halted at the end of the previous simulated week, into the workstation and executes. The model performs improvements according to the PM schedule and runs production. At the end of the simulation, the production data are sent to the MMS, and the status of the simulated department is saved for the next week's execution. The teams look at the productivity data using the MMS and make decisions about the next week's production and PM schedules.

Each team's goal is to improve performance in a number of areas: to meet customer requirements, to improve productivity by maximizing department efficiency, and to use a minimum of production hours. Teams must evaluate the productivity data in each decision period of the exercise, adjust their plans for the next period, and implement the appropriate actions.

The course has several objectives. The first is to demonstrate to students that to increase productivity, they must continuously perform structured analyses (Figure 4) to identify current bottlenecks based on recent and historical information from the MMS. Second, we emphasize preventive maintenance (PM). PM reduces the incidence of breakdown or failure in plant equipment, extends the useful life of production machinery, reduces the total cost of maintenance (PM avoids more costly repairs), promotes safe working conditions, and improves product quality by keeping equipment properly adjusted, well serviced, and in good operating condition.



Machine Maintenance

Operation	Station	Fault #	PM Hours
3_	4_	3_	10_
3_	5_	6_	10_
1_	5	2_	10_
1_	6_	4_	10_

Cycle Time Improvement

Operation	_2				
PM Hrs Assigned	10_				

Scrap Rate Improvement

Operation					
PM Hrs Assigned					

Total 8 hr. Production Days Avail. 7

Production Days to Run 5

Days Available for PM 2

Eight Persons Available for a total of : 128 PM hours

PM Hrs Scheduled 50

Unused PM Hours 78

Production Hours Saved 9.75

Figure 3: In this user interface screen, production is for five days (40 hours), leaving two days or 16 hours for preventive maintenance (PM). The number of PM hours for an eight-person PM team is 128. The team has scheduled 50 PM hours, 40 hours for machine maintenance and 10 hours for cycle-time improvement. The team has saved 9.75 unscheduled hours (dividing the 78 unused PM-hours by eight, the size of PM crew).

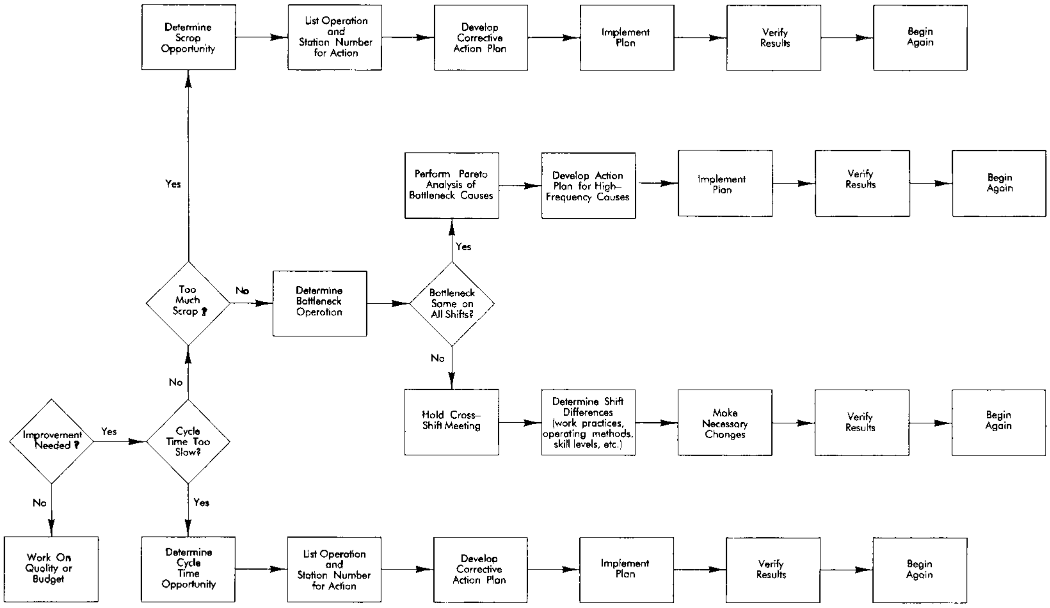


Figure 4: A production team should follow this flowchart for productivity-improvement actions to realize productivity improvement in the workplace.

Poor maintenance can make a company unable to implement a lean production system. It can also distort the picture of a plant's or a company's true production capacity. Klein and Rogers [1990] argue that the statistics for some industries show that excess capacity is available; rarely are there statistics that identify how much of this excess is actually usable.

We have conducted the Productivity 201 training classes at several plants. They have been very successful because the realistic tasks resemble those within the production facility and we provide information in a familiar format. The results have been outstanding. Because of its success and in response to requests from other plants, the corporate systems executives have decided to make the course a standard feature in distributing the MMS to 29 manufacturing plants worldwide.

Productivity Improvement in Front-Axle Production Line

At the end of 1996, Ron Holcomb was appointed assembly manager in charge of the front-axle production line. He had previously been the quality and system manager at the Ford Romeo engine plant and had helped to launch the MMS and the productivity training classes at the Romeo plant. He decided to use a fairly simple "model" that he used at the Romeo plant for getting results from the front-axle team. This model is called ABCs for getting results:

If you want results from people, give them

(A) Expectations (make sure they understand and agree on what results are expected);

(B) Results (make sure they get feedback on how their results compare to expectations); and

(C) Tools and resources (make sure they

have the tools and resources they need to make B equal A).

For Step A (Expectations), Ron Holcomb and George Pfeil taught employees about such measurables as overall equipment efficiency, standalone capability, and floor constraint identification. They offered the Productivity 201 training course to the front-axle team in January 1997. The team established the average hourly production rate for the last quarter (September to December 1996), 57 axles, as the baseline. It set an improvement target of 10 percent or an average hourly production rate of 63 axles.

In Step B (Results and Feedback), Holcomb created a form for the regular productivity meeting to review process and discuss results: a (mandatory) weekly one-hour session to be attended by Ron Holcomb, the production superintendent, the operators, the maintenance and process engineers, the quality analyst, machinery and equipment suppliers, and special guests as required. Holcomb carefully choreographed the meetings, allocating time to several specific discussions that focused on data (fact) instead of opinions. When data was not readily available, someone was assigned to collect or generate it before the next session. The group focused on the top five constrained operations in the line, those with the lowest standalone capability. It did this for two reasons: to ensure that it focused improvement actions on the bottlenecks (because, if you improve any operation other than the bottleneck, the only result you'll get is frustration) and to see how much improvement it could get and where to take the next actions. Finally, the group reviewed all open assignments to make sure nothing fell off the table. Not everyone conformed to the format of these meetings. Ron occasionally had to excuse individuals from meetings when they persisted in expressing their opinions, as opposed to relying on the MMS data, or they didn't allow others to express their views.

Productivity improved by more than 30 percent.

The last step in our simple ABC model was to provide tools and resources. The team studied the productivity data from the MMS each week. It used the productivity-improvement action plan (Figure 4) with techniques learned in the productivity-training class to detect and solve problems. Then the team prepared a plan of actions to overcome productivity problems. Often team members needed a simulation study to see the effects of proposed changes to the line and to study what-if questions. The simulation model was then updated with current information on the actual production line from the MMS, then modified for any proposed revision, and run to see the results of those changes (Figure 5). The simulation consultant ran the models, and the self-directed work team implemented the results. In general, the DSS empowered the team to carry out improvements to the line.

You may wonder if anyone opposed the development or use of the simulations? The answer is yes. The production superintendent did not believe in simulation modeling. He thought he knew what the bottleneck was (and was later proved

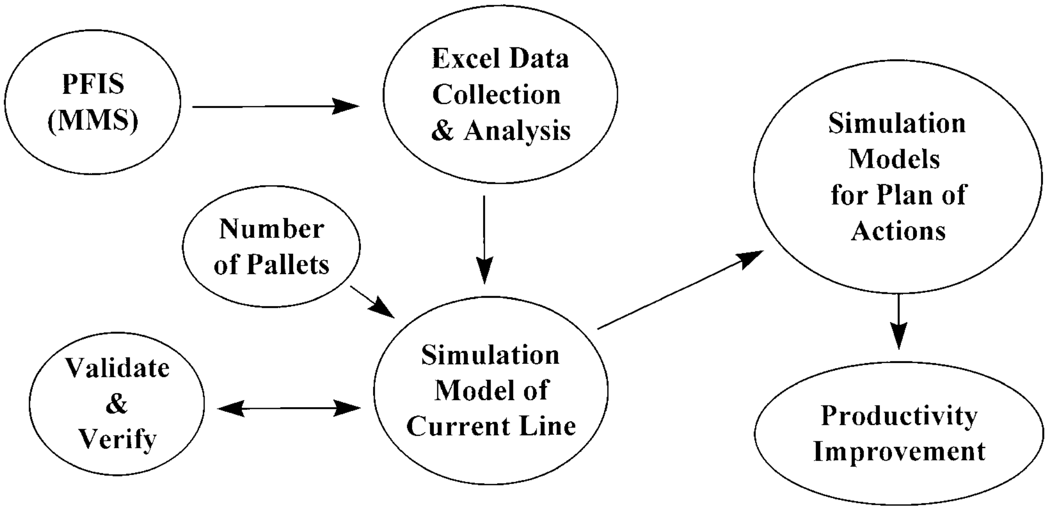


Figure 5: In the flowchart of the decision support system for productivity improvement, production data from the machine monitoring system (MMS) are captured in a spreadsheet for further analysis and for generating input data to the simulation models. Simulation models are then modified according to plans of action, and results are generated in a format similar to that of the MMS.

wrong). He became an advocate of simulation after he was surprised by results from the new decision-support system.

Our results greatly exceeded even our expectations. Productivity improved by 30 percent over 18 months (January 1997 through July 1998). The average production rate increased from 57 to 74.5 axles per hour, well beyond the 10-percent target we had established in January 1997. The line produced 144,496 extra axles because of this increase. The team accomplished this productivity improvement by attacking bottlenecks, reducing cycle time, improving uptime, reducing rejects, and improving incoming-part quality.

Simulation Modeling Approach

We used discrete-event simulation because we had a complex, dynamic, closed-loop production line with finite capacity between stations and different cycle times, downtimes, and repair-bay loops. We considered using optimization and queuing analysis, but because model users would likely investigate many diverse improvement ideas and the line was complex, we decided against those tools.

We simulated the front-axle production line in Witness simulation software. Witness is a powerful visual interactive simulation software with many built-in features for the manufacturing industry. We carried out the simulation projects at the plant with input from process engineers, the production superintendent, operators, and the MMS coordinator. We used process flows, actual cycle times, reject and tear-down rates, repair-bay logic, and machine downtimes for the foundation of the simulation models. The major source of historical information was the MMS archival data.

We modeled the stations as two-cycle machines. The first cycle is the RF-read cycle to check the status of the pallet. At the end of first cycle, the pallet is immediately released if it is empty, if it carries a rejected part, or if the part it carries has already undergone the operation (the pallet has been in the repair bay and is returning to the loop). The second cycle is the operation cycle. After the operation cycle, the part may be rejected if it does not meet the criteria of that station. In the simulation, a set of attributes is associated with each pallet to correspond to the status of the assembly it carries, such as reject, tear down, and operations already performed, and the status of the pallet itself, such as the number of complete circulations since the pallet wash cycle. These attributes are reset after the pallet is unloaded and after it is washed. To model downtime, we used two statistics: mean operations to failure (MOTF) and mean time to repair (MTTR). We calculated a station's MOTF by dividing good and bad part counts by fault occurrences and a station's MTTR by dividing the station's downtime by fault occurrences. In the simulation models, we generate the number of operations to failure and the repair time randomly using the negative exponential distribution and the Erlang 2 distribution, respectively. Other sources of randomness in the models are reject rates at stations and tear-down rates at the repair bays. To generate reject and tear-down rates randomly, we use uniform distributions, basing choice of distributions on goodness-of-fit calculations for the data. We have used independent random-number streams for unrelated distributions to obtain valid results.

We verified the simulation models in detail for accuracy. The simulation models we used are called nonterminating-production-line models [Law and Kelton 1991]. There are two alternatives for obtaining valid simulation results in practice. According to Hwa-Sung Na [1996], the head of Ford's simulation user group, one alternative is to run the simulation long enough to reach steady state and obtain valid results. If long runs are not feasible, then one must use repetition. Averages from multiple runs should be used to support decisions. It is clear that the longer the runs, the less variation in results reported. Thus, the results are less likely to be influenced by the choice of random-number streams in the model. We decided to use long runs rather than replications for the practical reason that we wanted to produce results similar to those in the MMS reports. To determine how long is long enough to assess the impact of randomness on the system, seasoned simulation practitioners recommend a rule of thumb: simulation run time should be long enough to obtain at least 10 occurrences of the random and significant event that occurs least often. In our simulation models, station downtime is the event that occurs least often.

The group validated every simulation model, walking through the animation and simulation results and actual system performance. The simulation results were delivered in a format similar to MMS for ease of understanding and implementation.

Example

As an example of the process, in May 1997, the front-axle team requested a simulation study for a series of proposals for productivity improvement. The MMS data for the first 14 days of May showed average hourly production (JPH) of 78.38 and average hourly tear downs (TPH) of 5.15 (Table 1). Automatic-station cycle time varied from 11.8 to 33.7 seconds, except for the duplicate stations 17 and 18, which were 61.5 and 59.4 seconds, respectively. We entered the MMS data into a spreadsheet that computes MOTF, MTTR, and repair-bay statistics. We then entered that information, along with the number of pallets, the station cycle times, and the station reject rates (from the MMS) into the simulation model. We ran the simulation model and compared the results to actual line production. The simulated model yielded an average JPH of 78.80 and an average TPH of 5.34 data (Table 2). The 95-percent confidence intervals for JPH and TPH are (77.71, 79.89) and (5.06, 5.62), respectively. The model's estimate of the JPH is within 0.5 percent of the actual observation. This result is outstanding because of the accuracy in MMS data and in the simulation model. The simulation result also resembles the MMS report. After verifying the simulation model, we modified it to reflect a series of scenarios from the team's plan of actions. First, we ran the simulation model with several different numbers of pallets to see the effect on JPH. An important question was what number of pallets in the system would result in the highest production rate. When the number of pallets is small, the production rate is low because the stations are starved for parts. On the other hand, when the number of pallets is large, the production rate is again low because the stations are blocked most of the time. Increasing the number of pallets decreases the starvation of the machines, which has a positive effect on the production rate, but increases the blocking, which has a negative effect. Up to a certain number of pallets, the positive effect is more important than the negative one, which explains why the production rate rises, and beyond this number the production rate falls. We wanted to find the number of pallets that would yield the highest production rate. We found that productivity increased when we reduced the number of pallets from 116 to 90 (Table 3). The JPH increased from 78.80 to a maximum of 81.24 with 90 pallets. Reducing the number of pallets below 90 decreases the JPH. The maximum productivity increase is 2.44 JPH or about 3.1 percent. A very interesting finding is that several values for the number of pallets yield the maximum production rate. In our study, we found that three values for the number of pallets, 100, 95, and 90, gave almost the same JPH. Frein, Commault, and Dallery [1996] reported the same results.

The simulation results included various productivity-improvement initiatives. An important tool for identifying bottlenecks is the stand-alone capability (SAC) analysis. The SAC shows the maximum capability of an operation (parts per hour) if it is never blocked or starved. The SAC is computed using the following formula:

$$\text{SAC} = (\text{Good Part Count}/\text{Production Run Time}) \times (\%\ \text{Uptime}/\%\ \text{Cycle}).$$

Good part count (GPC) is the total number of good parts produced not including rejects. We get hourly GPC by dividing the GPC by the production run time. This hourly GPC is then credited for the blocked and starved time by multiplying it by the ratio of percent uptime over percent cycle time (productive time). Uptime refers to the time that station was in cycle (productive), blocked, or starved. We calculated the SAC for Station 1 by first di-

	Down								
Machine	Time	Occ	Reject Parts	Good Parts	Cycle Time	% Rej	MOTF	MTTR	SAC
01 Ld Carr	2,217	1241	—	22,871	28.3	0	18	1.79	113
02 Untqe	536	432	—	22,811	22.6	0	53	1.24	154
03 Ld Gear	1,223	540	1	22,853	30.3	0	42	2.26	113
04 Prs Gr	327	147	220	22,794	24.4	1	157	2.22	145
07 Ga Case	582	442	349	22,606	33.4	1.5	52	1.32	103
08 Pl Cone	963	832	102	22,501	32.1	0.5	27	1.16	105
09 Pr Cone	157	166	1	22,506	15.1	0	136	0.95	237
10 Inv Car	1,091	540	—	22,500	27.6	0	42	2.02	122
11 Prs Flg	142	66	1,626	20,860	25.1	7.2	341	2.15	132
13 Tq Nut	220	182	138	22,367	33.7	0.6	124	1.21	104
14 Inv Car	77	69	—	22,415	26.8	0	325	1.12	134
15 Lk Test	289	91	1,103	21,823	31.5	4.8	252	3.18	107
16 Rb 1 En	275	122	3,383	23,152	8.0	12.7	218	2.25	122
17 Ins Cas	1,252	342	8	10,966	61.5	0.1	32	3.66	54
18 Ins Cas	976	236	7	10,874	59.4	0.1	46	4.14	57
19 Tq Caps	86	29	50	21,796	31.3	0.2	753	2.97	114
20 Run Pat	119	40	60	22,914	31.2	0.3	574	2.98	114
21 Insp Pa	1,932	1035	1,227	21,565	31.0	5.4	22	1.87	99
22 Prs Brg	281	56	19	21,567	29.1	0.1	385	5.02	122
23 Lh Shft	1,706	1210	126	21,481	32.1	0.6	18	1.41	102
24 Push/Pu	44	25	54	21,452	21.8	0.3	860	1.76	164
25 Rb 2 Ex	218	154	1,775	21,465	8.0	7.6	151	1.42	165
26 Rot 180	2	2	—	22,883	13.2	0	11,442	1.00	273
27 Ld Kt 2	1,567	843	47	21,496	28.7	0.2	26	1.86	116
28 Rh Shft	1,789	792	10	21,495	31.5	0	27	2.26	104
29 Tq Shft	258	95	648	20,791	23.2	3	226	2.72	148
30 Ins Vac	1,382	739	116	21,442	32.9	0.5	29	1.87	106
32 Sus Bsh	250	115	2	21,535	29.0	0	187	2.17	122
33 Lube Fl	171	114	101	21,531	28.4	0.5	190	1.50	125
34 Tq Covr	942	223	1,382	20,823	29.9	6.2	100	4.22	109
35 Lk Test	677	213	674	21,396	29.6	3.1	104	3.18	113
36 Rb 3 En	417	281	979	21,478	8.0	4.4	80	1.48	240
37 Ins Plg	673	373	—	22,862	11.8	0	61	1.80	150
38 Unload	857	444	1,407	21,422	31.9	6.2	51	1.93	110

Table 1: The MMS production summary report for the front-axle production line displays partial productivity information for May 1–14, 1997. It shows for each station downtime in minutes and number of occurrences, number of rejected parts, number of good parts, cycle time in seconds, percent rejects, mean operations to failure (MOTF), mean time to repair (MTTR) in minutes, and stand alone capability (SAC). The production run was 273.3 hours, yielding an average jobs per hour (JPH) rate of 78.38 and an average tear-down per hour (TPH) rate of 5.15.

Station	% Starved	% Cycle	% Blocked	% Down	GPC	Reject	F-OCC	GPC/Hr	Uptime	SAC
STA001	5.06	66.48	14.79	13.69	23,108	—	1,272	84.55	86.33	110
STA002	16.49	53.06	26.94	3.50	23,104	—	439	84.54	96.49	154
STA003	5.93	71.15	15.32	7.61	23,099	—	558	84.52	92.41	110
STA004	16.32	57.29	24.44	1.96	22,861	237	143	83.65	98.04	143
STA007	2.25	77.62	16.61	3.51	22,519	334	443	82.40	96.48	102
STA008	3.45	73.59	17.19	5.79	22,410	106	812	82.00	94.22	105
STA009	16.51	34.52	47.94	1.03	22,407	—	185	81.99	98.96	235
STA010	3.51	62.98	26.58	6.93	22,402	—	562	81.97	93.07	121
STA011	9.47	57.28	32.51	0.73	20,670	1,731	55	75.63	99.26	131
STA013	0.59	76.95	20.99	1.45	22,079	119	186	80.79	98.53	103
STA014	6.01	61.38	32.09	0.53	22,184	—	79	81.17	99.48	132
STA015	1.33	71.95	24.37	2.35	21,055	1,125	116	77.04	97.65	105
STA016	14.46	7.67	77.86	0.00	23,146	3,651	—	84.69	100.00	1104
STA017	1.23	66.62	24.98	7.17	10,286	10	335	37.64	92.83	52
STA018	2.06	73.16	19.25	5.52	11,726	10	228	42.91	94.48	55
STA019	4.55	70.30	24.81	0.36	21,968	53	27	80.38	99.66	114
STA020	2.89	70.03	26.49	0.58	21,938	79	33	80.27	99.40	114
STA021	2.03	69.53	16.59	11.84	20,863	1,132	1,044	76.34	88.16	97
STA022	10.41	64.67	23.09	1.83	21,743	28	57	79.56	98.17	121
STA023	6.26	71.28	12.02	10.44	21,625	135	1,236	79.13	89.57	99
STA024	27.47	48.43	23.85	0.27	21,669	55	25	79.29	99.74	163
STA025	36.44	5.86	57.69	0.00	21,714	1,449	—	79.45	99.99	1356
STA026	16.66	29.40	53.94	0.00	21,714	—	—	79.45	100.00	270
STA027	5.31	63.59	21.25	9.83	21,660	53	869	79.25	90.16	112
STA028	3.69	69.61	15.19	11.51	21,656	—	833	79.24	88.49	101
STA029	22.20	51.33	25.19	1.27	20,972	683	87	76.74	98.72	148
STA030	9.14	73.02	9.68	8.15	21,545	107	719	78.83	91.85	99
STA032	12.29	64.35	21.71	1.65	21,675	1	128	79.31	98.35	121
STA033	9.30	63.02	26.59	1.09	21,581	93	122	78.96	98.91	124
STA034	5.54	66.25	22.65	5.56	20,285	1,362	222	74.22	94.44	106
STA035	8.85	65.59	21.26	4.30	20,970	675	227	76.73	95.70	112
STA036	24.58	5.43	69.99	0.00	21,545	928	—	78.83	100.00	1452
STA037	11.21	26.13	59.15	3.50	21,541	—	354	78.82	96.50	291
STA038	3.04	70.12	21.93	4.90	21,536	—	413	78.80	95.09	107

Table 2: These simulation results show the productivity information for the front-axle line: statistics of machine states (percent starved, percent blocked, percent cycled, percent down), good part count (GPC), number of rejects, fault occurrences, GPC per hour, percent of uptime, and stand alone capability (SAC). The simulated line was run with 116 pallets for 273.3 hours. It yielded an average job per hour (JPH) rate of 78.80 and tear-down per hour (TPH) rate of 5.34.

viding its GPC, 23,108 parts by the 273.3 hours (simulation run time), resulting in 84.55 GPC per hour (Table 2). Next we compute the ratio of percent uptime (5.06 + 66.48 + 14.79) over percent cycle time (66.48), which is 1.30. Finally, we obtain

	No. of Pallets	Total Production	Total Teardown	JPH	TPH	JPH GAIN
Existing line—Actual production	116	21,422	1,407	78.38	5.15	
Existing line—Simulation	116	21,536	1,460	78.80	5.34	
Changing number of pallets						
Base line—Simulation	116	21,536	1,460	78.80	5.34	—
Existing line—Simulation	105	22,077	1,492	80.78	5.46	1.98
Existing line—Simulation	100	22,193	1,496	81.20	5.47	2.40
Existing line—Simulation	95	22,179	1,496	81.15	5.47	2.35
Existing line—Simulation	90	22,203	1,496	81.24	5.47	2.44
Existing line—Simulation	85	22,190	1,496	81.19	5.47	2.39
Existing line—Simulation	80	22,134	1,493	80.99	5.46	2.19
Existing line—Simulation	70	21,817	1,477	79.83	5.40	1.03
Productivity improvement						
Base line	100	22,193	1,496	81.20	5.47	—
CTR for St 21 & 23 & new downtime	100	22,673	1,526	82.96	5.58	1.76
CTR for St 17 & 18	100	22,193	1,496	81.20	5.47	0.00
CTR for St 34	100	22,205	1,496	81.25	5.47	0.04
All of the above	100	22,706	1,528	83.08	5.59	1.88

Table 3: The simulation results of the front-axle line show the model performance is very close to the actual line performance. We ran the simulated line for 273.3 hours for several productivity-improvement action plans. There were too many pallets in the system. The team realized that optimizing the number of pallets would provide more gain than other productivity-improvement actions, such as reducing a station's cycle time (CTR).

the SAC for Station 1, 110 parts per hour, by multiplying 84.55 by 1.30. Operations with low SAC are production bottlenecks. Stations 21 and 23 are the bottlenecks, with low SACs of 97 JPH and 99 JPH. Stations 17 and 18, with SACs of 52 and 55, are not bottlenecks, however; they are parallel operations with a combined SAC of 107 JPH.

Reducing cycle times for stations 21 and 23 in the simulation model resulted in a net JPH gain of 1.76. Improving stations 17 and 18 did not increase production in the simulated model, because they are not bottlenecks.

After seeing the simulation results, the team decided to reduce the number of pallets from 116 to 100, but the results did not justify reducing cycle times for stations. The production people always thought that by adding pallets they could increase line output. Simulation proved otherwise.

The innovative parts of our DSS are direct connection of the MMS to the simulation model and the production team's ability (after training) to use this data to identify and implement productivity improvements.

Capacity Expansion Study of the Front Axle

A series of proposals were made in 1996 to expand and modify the line to keep up with demand. Visteon managers asked Shahram Taj to simulate the existing line and the proposed expansion. After running the simulation model of the existing line, he compared the results to the actual numbers. Actual production of the line for October 1 through 15, 1996 showed an average hourly production rate (JPH) of 64.67 and average teardowns per hour (TPH) of 7.86. The average JPH and average TPH in the simulated model were 65.54 and 7.82, respectively. The 95-percent confidence intervals for JPH and TPH are (64.49, 66.59) and (7.55, 8.10) respectively. The result was remarkable: the performance of the simulation model was almost identical to that of the actual line (within one percent). This close proximity of the model to the real world was due mainly to the accuracy of the MMS data and modeling details in the simulation. Taj modified the simulation model to reflect several proposed expansions, such as adding new stations, having parallel lines for duplicate stations, reworking several stations, and adding buffers at several sections in the line. The simulation showed that the average JPH for the expansion models would be about 96 JPH. These results showed that the expansions could not increase the productivity of the line to meet the new required annual volume of 550,000 units. This information was valuable, causing Visteon to drop the expansions. The cost of the proposed expansions of the line was about $10 million, and installation would have taken several months.

After deciding against expanding the line, the managers decided to install another production line, called Gemini, to increase capacity. We applied the simulation-based DSS from the early stage of the design to the final launch of the Gemini line. We applied the lessons learned from the productivity improvements to the design of the new line. As a result, the line was designed with reduced automation, fewer stations, proven technology, easier maintainability, and more space between stations.

Table 4 shows the simulation results for the Gemini line. The line is capable of an average of 80 JPH (with a 95-percent confidence level of 1.06). We applied productivity improvement while the line was in the design phase using the simulation-based DSS to determine the optimum number of pallets, the spacing between stations, alternative tear-down policies at repair bays, and the effect of adding buffers in several sections of the line before and after the constrained stations (Table 4).

We achieved higher productivity at a lower investment cost for the Gemini line in comparison to the old line, with a capital savings of $5.5 million. We are now able to produce front axles on both lines, which jointly are capable of production volume that is 160 percent of the volume for the single line in 1996. This increased production capability allows Ford to meet the increased demand for 4 × 4 SUVs.

Benefit

The key to productivity improvement was the combination of

—training;

—the MMS;

—simulation; and

—an empowered work team.

The simulation-based productivity-training class taught the team that it must use structured analysis and actual MMS data to improve productivity, rather than relying on subjective opinions or hunches. The simulation-based DSS helped the team to discover correct fixes, prevented Visteon from wasting time and resources on nonbottleneck operations, prevented Visteon from investing in an unproductive line expansion, suggested how Visteon should design the new line, and empowered the team. The DSS had the following quantitative and qualitative impacts:

(1) Productivity improved by more than 30 percent. The line produced an "extra" 144,496 front axles from January 1997 through July 1998 because of the productivity improvement.

(2) Ford Motor Company increased its profits because it was able to respond to market demand for 4 × 4 F-series trucks, Ford Expeditions, and Lincoln Navigators. Ford was the only big-three automaker that reported increased third-quarter earnings in 1997, due to sales of its Ford Expedition and Lincoln Navigator [Ha 1997].

(3) Visteon avoided spending $10 million on retrofits to the front-axle line that would have been inefficient.

(4) Visteon saved $5.5 million on the purchase of a new front-axle line.

(5) Ford has become the market leader in full-sized SUVs because of high-volume sales of the Ford Expedition and Lincoln Navigator.

(6) The Lincoln division has increased its market share mainly due to strong sales of the Navigator, and it has overtaken Cadillac as the luxury sales leader in 1998.

(7) The decision-support system empowered the self-directed work group and drives a continuous-improvement mindset.

(8) The spirit of the empowered self-directed work team has proven to be a strategic competitive advantage. As potential customers from around the world visit

Productivity Improvement	No. of Pallets	JPH	TPH	JPH GAIN
Base line	75	80.01	2.25	—
Removing empty pallets form RB #1 & #2	75	80.70	2.02	0.69
Replacing tear-down at repair bays	75	81.24	0.00	1.23
Change conveyor ahead stations 13 & 14	75	80.01	2.25	0.00
Change conveyor ahead stations 25, 26, 27, & 28	75	80.29	2.26	0.27
Productivity improvement				
Base line	85	80.26	2.25	—
Buffer of 6 before and after stations 3, 8, 20, 26	85	81.75	2.28	1.49
Buffer of 6 before stations 3, 8, 20, 26	85	81.01	2.27	0.75
Buffer of 6 before station 3	85	80.47	2.26	0.21
Buffer of 6 before station 8	85	80.23	2.25	−0.04
Buffer of 6 before station 20	85	80.56	2.27	0.30
Buffer of 6 before station 26	85	80.55	2.27	0.29

Table 4: The simulation results for the new (Gemini) front-axle line show the average job per hour (JPH) rate and average tear-down per hour (TPH) rate for different numbers of pallets and productivity-improvement plans. We applied simulation from the early stage of the design and applied improvement actions while the line was being built to achieve higher productivity with reduced investment cost.

our plant and tour the front-axle production line, they can't help but be struck by the knowledge and enthusiasm of the work group.

(9) Finally, by achieving the increase in throughput in its front-axle production line, the Sterling plant demonstrated that it could rise to a tough challenge in managing high-tech production lines.

Portability

The simulation- and MMS-based decision-support systems are highly portable to other manufacturing plants inside and outside of the company. The "Productivity 201" training developed at the Romeo engine plant, imported and enhanced at the Sterling plant, has been transferred to other manufacturing plants. The synergy that results from combining OR/MS tools, plant-floor information systems, productivity training, and empowered work teams can be achieved in most manufacturing environments.

Conclusion

In today's world economy, continuous pressures encourage manufacturing companies to review manufacturing operations as their most important strategic competitive advantages. To utilize manufacturing facilities successfully, they need better trained workforces. Managers must provide these workforces with training and useful experience. They must raise productivity levels if their companies are to prosper. Peter F. Druker [1991, p. 69] says that

> "The single greatest challenge facing managers in developed countries of the world is to raise the productivity of knowledge and service workers. This challenge, which will dominate the management agenda for the next several decades, will ultimately determine the competitive performance of companies. Even more important, it will determine the very fabric of society and quality of life in every industrialized nation."

Information systems can provide organizations with many opportunities to improve their productivity. In a modern factory, information is already available on a real-time basis. The challenge is to discover how to use information to solve problems in a continuous-improvement environment. As computer-integrated manufacturing (CIM) becomes the norm in plants and experience with CIM adoption increases, an untrained workforce is a serious liability. Companies can change this situation by giving top priority to investments in talent, education, training, and motivation of people.

The goal is to develop knowledgeable workforces that can use information systems properly in day-to-day activities and problem solving. This is most important in pull-production or just-in-time environments. Without knowledgeable workforces, a single production line going down could have a domino effect on other production lines in the plant and could soon halt the operation of other plants in the chain.

In our case, the combination of the MMS, simulation technology, productivity training, and the empowered work team were key elements in our ability to achieve

—lean, reliable processes;
—information systems that provide workers with the information they need; and
—the skilled, motivated workforce that we need to be the best.

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During the competition, Ray Schaffart, Vice President and General Manager, Visteon Chassis Systems, Visteon Automotive Systems, SE61-P07, 6100 Mercury Drive, Dearborn, Michigan 48126, stated: "They applied these principles on a relatively new operation at Sterling. What happened, is the customer demand was about 35% to 40% greater than the installed capacity, and in this industry when you have a hot vehicle you want to take advantage of it. So they were challenged with trying to get that kind of increase, literally overnight.

"Everything they were able to do actually helped us in the design of the next generation manufacturing system, saving $5.5 million in a cost of that installation along with avoiding $10 million in retrofitting the existing system. Very substantial savings and very positive impact for our customer."

Mike Newbury, Controller, Visteon Chassis Systems, writes: "Our customers are demanding never-ending improvement in quality, cost, and delivery performance. Without applying advanced OR/MS technology to the manufacturing shop floor, we will never be able to be successful in this industry."

Executive summaries of Edelman award papers are presented here. The complete article was published in the INFORMS journal Interfaces [2000, 30:1, 115-133]. Full text is available by subscription at http://www.extenza-eps.com/extenza/contentviewing/viewJournal.do?journalId=5