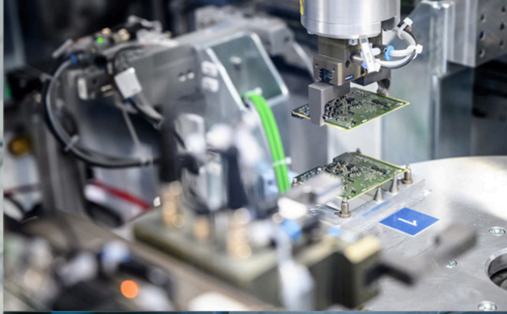

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Electronics system-assembly simulation

Using simulation to optimize throughput and cost of system assembly and work cells

Executive summary

Electronics assembly can be delivered at competitive market prices only as long as the manufacturing process is continuously improved. With the help of Industry 4.0 and simulation tools, manufacturing companies are mastering a high degree of variance, continuously shrinking batch sizes and fluctuations in order volume that are increasingly difficult to predict. The word "simulation" is defined as the computer-based modeling of the operation of a real-world process or system over time. With this definition in mind, it is easy to understand why simulation is ubiquitous in engineering and industrial organizations; imitating a real-world process or system that allows experts to study the process or system they are interested in within a controlled environment. How can we use manufacturing simulation to optimize electronics assembly manufacturing?

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Abstract

Simulation allows companies to identify manufacturing bottlenecks and opportunities to increase throughput, identifying cost savings opportunities such as optimization of direct and indirect labor, managing inventory levels and validating the expected performance of new or existing production facilities or value streams. Manufacturing simulation consists of plant simulation and process simulation. Plant simulation enables studies of material flows, bottleneck analysis at the area and line level, movement optimization, automated guided vehicle (AGV) movement simulations and resource optimization studies. Process simulation enables studies of processes and operations to optimize sequencing of operations, robot and collaborative robot ("cobot") operations, spatial risk analysis when humans are close to robots and cobots, and ergonomics simulation for optimal human movement. Simulation ensures compliance with lean manufacturing methodologies and removal of waste. In this whitepaper we answer the question: Is manufacturing simulation applicable and effective in electronics assembly manufacturing?

This paper describes the design and implementation of several manufacturing simulation use cases at an electronics assembly factory in Nanjing, China. This factory has six surface mount lines, a fairly high product mix and variants, and also requires some high-volume production. Also, they have integrated circuit (ICT) and system tests, manual assembly lines, software loading stations, box-build cells, packing and labeling, shipping and aftermarket service and depot repair. The chosen factory is an ideal candidate for testing the effectiveness of manufacturing simulation in electronics manufacturing. We describe the use cases, the approach, key performance indicators (KPIs) used to monitor progress, changes made to production and the results of the theoretical simulation versus actuals. We will also discuss using the digital twin of the factory and processes in additional use cases, such as sales evaluation and estimation validation. Finally, we publish results that may be used as an example of how other factories can use simulation to optimize throughput and cost to make steps forward in their digitalization journey

Increasing efficiency

The purpose of value-stream (VSM) is to identify and remove or reduce waste in value streams, thereby increasing the efficiency of a given value stream. Waste removal is intended to increase productivity by creating leaner operations, which in turn make waste and quality problems easier to identify. Typically, value-stream mapping is used to visualize all critical steps in a specific process and quantifies the time and volume taken at each stage. Value stream maps show the flow of both materials, capacity calculations and related information as they progress through the process.

Manufacturing simulation

According to Wikipedia, “A simulation is an approximate imitation of the operation of a process or system; that represents its operation over time ...A computer simulation (or “sim”) is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables in the simulation, predictions may be made about the behavior of the system. It is a tool to investigate the behavior of the system under study virtually. Traditionally, the formal modeling of systems has been via a mathematical model, which attempts to find analytical solutions enabling the prediction of the behavior of the system from a set of parameters and initial conditions. Computer simulation is often used as an adjunct to, or substitution for, modeling systems for which simple closed form analytic solutions are not possible.”

In electronics manufacturing most factory simulations are done with combinations of Microsoft Excel spreadsheet software models and some software to assist with the complexity of the computation of a dynamic system, which tends to drive relatively limited scenario studies. Typical use cases that are ideal for manufacturing simulation can answer questions such as:

- How much would additional throughput be gained with an extra shift or resource
- How much additional throughput would be gained by adding additional cells, stations, etc.
- Is there a point at which there are diminishing returns with capacity and stations
- Is my material delivery route ideal for station X or line Y
- How much buffer is created if I set the conveyor speed to X? Does it lead to additional throughput
- Is the distribution of parts in manual assembly cells optimal for the expected throughput
- Are there bottlenecks in the box-build assembly cell due to ergonomic challenges? Material access challenges
- Can we increase quality by putting a collaborative robot at a station/cell? Are there any risks in the sequence programming

The process of performing manufacturing simulation requires several steps. Figure 1 outlines a typical workflow.

Define system

At the core of any simulation study is the objective and target of the study. This may be a manual assembly cell, a line, the full factory, the material flow within an area, or even a specific cobot at a station.

Map processes

Mapping or characterizing the system that is the focus of the study requires a methodology. As mentioned earlier, the purpose of value-stream mapping is to identify and remove or reduce waste in value streams, thereby increasing the efficiency. (VSM) is used to visualize all critical steps in a specific process and quantifies the time and volume or throughput taken at each stage. VSM is a lean manufacturing technique to

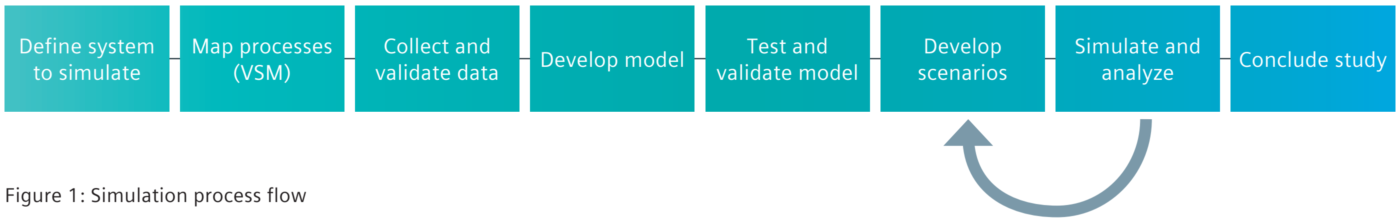


Figure 1: Simulation process flow

analyze, design and manage the flow of materials and information required to bring a product to a customer. VSM uses a system of standard symbols to depict various work streams and information flows.[1]

Collect and validate data

Data that should be collected depends on the objectives of the study and the system to be studied. Typical information collected may include: speed, capacity, volume, throughput, quality, number of units in buffers, etc. Data is collected in a spreadsheet using either Microsoft Excel or similar tools to organize the data on which analysis can be run. The purpose of collecting data and performing the study is to optimize processes and remove waste, thereby optimizing costs for production. The commonly defined types of waste include[2]:

1. **Faster-than-necessary pace:** Creating too much of a good or service that damages production flow, quality and productivity. Referred to as overproduction, this leads to storage and lead-time waste.
2. **Waiting:** Anytime goods are not being worked on or transported.
3. **Conveyance:** The process by which goods are moved. Referred to as transport, this includes double-handling and excessive movement.
4. **Processing:** An overly complex solution for a simple procedure. Referred to as inappropriate processing, this includes unsafe production. This typically leads to poor layout, poor communication and unnecessary motion.
5. **Excess stock:** An overabundance of inventory that results in greater lead times, increased difficulty identifying problems and high storage costs.
6. **Unnecessary motion:** Ergonomics waste that requires employees to use excess energy such as picking up objects, bending, or stretching. Referred to as unnecessary movements, this is usually avoidable.
7. **Correction of mistakes:** Any cost associated with defects or the resources required to correct them.

Any endeavor to define which data to collect should have the above waste in mind, in addition to the data required to analyze and create a simulation model closest to the study objectives.

Develop model

The model development stage is when the benefits of computerized model development and visualization are most apparent. First, the characterization and entry of the VSM of the study should be done. Then the table of results should be referenced within the study. At that stage, the manufacturing simulation software can be used to perform simulations. Most manufacturing simulations use discrete-event simulation techniques.

A discrete-event simulation (DES) models the operation of a system as a discrete sequence of events in time. Each event occurs at an instant in time and marks a change of state in the system. Between consecutive events, no change in the system is assumed to occur; thus, the simulation time can directly jump to the occurrence time of the next event, which is called next-event time progression, according to Wikipedia's definition. In the real world, time passes continuously. For instance, when watching a part move along a conveyor system, you will detect no leaps in time. The time the part takes to cover the system is continuous, such that the curve for the distance covered is a straight line. A DES program, on the other hand, only takes into consideration those points in time (events) that are important to the further course of the simulation. Such events may, for example, be a part entering a station, leaving it, or moving on to another machine. One major advantage of DES over time-oriented simulation (continuous or time-step simulation) is performance. Since the program can skip all the moments in time that are not of interest, it is possible to simulate years of factory operation in just minutes. That is particularly useful when you want to simulate different configurations of the same system and make several replications for each configuration.[3]

For our use cases in this paper, we used the Tecnomatix® portfolio, including the Tecnomatix Plant Simulation module and Tecnomatix Process Simulate module by Siemens Digital Industries Software. They have the following capabilities that were leveraged to provide the analysis and results:

- Object-oriented models with hierarchy and inheritance
- Open architecture with multiple interface support

- 3D capable visualization (using the JT™ data format)
- Library and object management
- Discrete-event simulation analysis and visualization
- A genetic algorithm for optimization
- Energy consumption simulation and analysis
- Value-stream mapping and simulation
- Automatic analysis of simulation results
- Quick scenario definition and iteration
- HTML-based report builder

Also, for this study, NX™ software, Line Designer module was used to generate the 2D and 3D machine models and line models for visualization. Since Tecnomatix Plant Simulation (Plant Simulation) and Tecnomatix Process Simulate (Process Simulate) can be used to import any 2D and 3D models using the standard JT modeling language, other computer-aided design (CAD) tools may be used. According to Wikipedia, JT (Jupiter Tessellation) is an International Organization for Standardization (ISO) 3D data format for product visualization, collaboration, CAD data exchange, and sometimes for long-term data retention. It can contain any combination of approximate (faceted) data, boundary representation surfaces (NURBS), product and manufacturing information (PMI), and metadata (textual attributes) either exported from the native CAD system or inserted by a product data management (PDM) system. In 2012 JT was officially published as ISO 14306:2012.

Manufacturing simulation modeling and available related software is an excellent way of analyzing and optimizing dynamic processes. Specifically, when mathematical optimization of complex systems becomes infeasible, and when conducting experiments within real systems is too expensive, time-consuming, or dangerous, simulation becomes a powerful tool. The aim of simulation is to support objective decision making with dynamic analysis to enable managers to plan their operations safely and save costs.

Develop scenarios

Once the simulation results are validated against the real-world data set within an acceptable tolerance, we develop study scenarios. Scenarios are the list of variables to change and investigate results. In some cases, this may include:

- Testing different number of shifts
- Testing different number of resources (stations, operators, cells, etc.)
- Moving AGV routes
- Changing Kanban locations
- Adding/removing assets
- Adjustments to speeds (conveyor, material delivery, etc.)
- And many more

Iterating these study scenarios, reviewing the results and providing management reports allows simulation studies to provide value to the organization.

Applicability in electronics manufacturing

The study and related results for this paper were done at Siemens Numerical Controls Ltd. (SNC). Established in 1996, Siemens Numerical Control Ltd., Nanjing[4] is a joint venture between Siemens and CNGC. Since its establishment, SNC has become a top-ranked supplier of factory automation systems as well as machine tool systems. SNC develops and manufactures numerical control systems, drives, human machine interfaces (HMI) and programmable logic controllers (PLC) that meet the special requirements of customers in China, Southeast Asia and other markets that require world-class quality standards. SNC employs about 1,300 in its China factories and has a production area of about 48,000 square meters (m^2). The production area consists of:

- Six surface-mount technology (SMT) machines
- Two wave soldering machines
- Three multi-wave soldering machines
- Seven ultraviolet (UV) coating machines
- More than 15 assembly lines

Use cases for this study

There were several use cases identified for this study as part of leveraging manufacturing simulation to improve throughput and cost. Based on initial bottleneck studies performed at the factory, three main areas were identified as opportunities for improvement: 1) Capacity simulation of wave soldering machines, 2) Logistics material flow simulation and 3) UV coating robot automation.

Capacity simulation of wave soldering machine

SNC currently has five wave solder stations that are fed through several manual insertion lines. Their current model does not account for peak loads, conveyor speeds, capacity variances and a few other factors. They collected data and analytics from the factors during production. Table 1 below describes the quantity of throughput forecasted during the period of the study.

Wave station	Quantity	Product
S1	7,241	FSA F, FSB
S2	9,811	FSCDE
S3	9,716	FSAU
S4	14,646	V70, V90, FSAB
S5	9,952	V70, V90, FSCD, CBO
Total	**51,366**	

Table 1: Initial throughput forecast.

Figure 2 illustrates the VSM created by describing how the different SMT lines (sources) fed the manual insertion lines and on into the wave solder machines.

Plant Simulation reported current state simulation results of 48,485 units, rather than the forecasted 51,186 units. The simulation output is illustrated in figure 3 for both capacity (throughput) as well as utilization.

It was obvious that production targets would not be met. With the use of the simulation software, the team was able to quickly determine two alternative strategies (scenarios), which were designed and tested. The results of the alternative scenarios are described in figure 4.

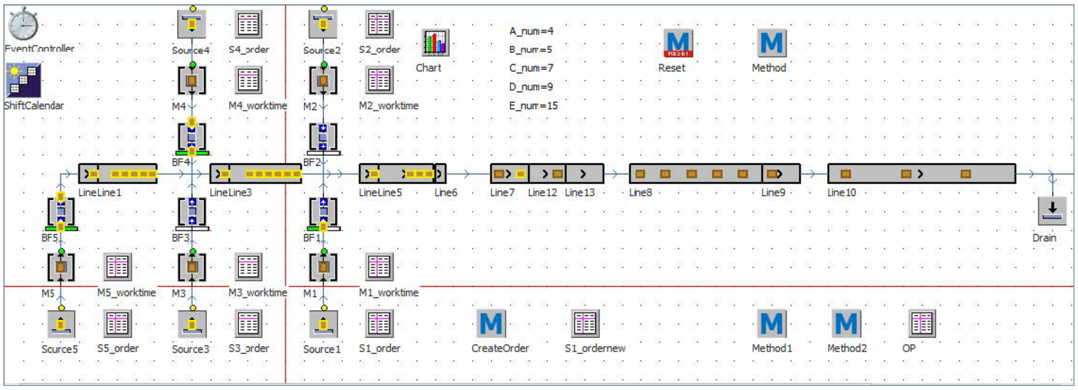
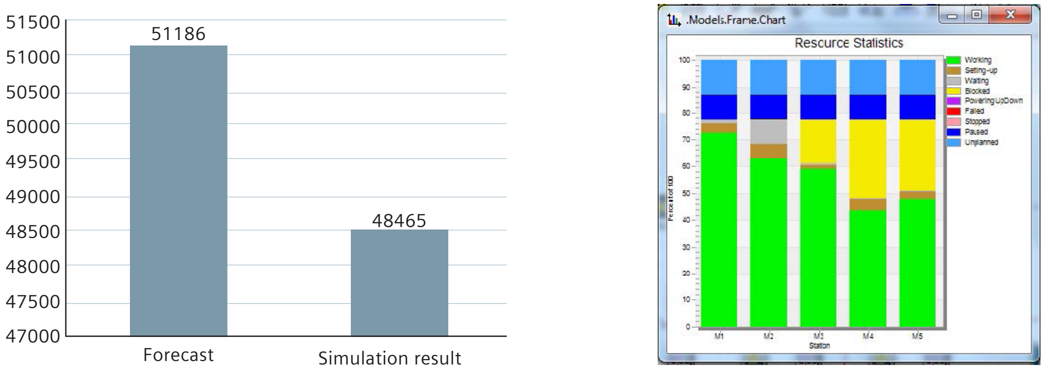


Figure 2: VSM for manual insertion lines and wave solder process



Capacity

Ultilization

Figure 3: Initial simulation results

Original

Product type	Station
FSA F	S1
FSB	S1
FSA U	S3
FSCDE	S2
V70V90 FSAB	S4
V70V90 FSCD/CBO	S5

Strategy 1

Product type	Station
FSA F	S3
FSB	S3
FSA U	S1
FSCDE	S4
V70V90 FSAB	S2
V70V90 FSCD/CBO	S5

Strategy 2

Product type	Station
FSA F	S3
FSB	S3
FSA U	S1
FSCDE	S2
V70V90 FSAB	S4
V70V90 FSCD/CBO	S5

Figure 4: Study scenarios defined.

Both scenarios were input into the simulation software and the resulting output analyzed. The results are in figure 5. Strategy 1 led to the best throughput.

However, in addition to throughput, utilization should be analyzed to ensure the simulation led to the best of both utilization and throughput factors for the products in the study. The results of the utilization analysis are described in figure 6.

The next step was to confirm the validity of this simulation. An experiment was conducted according to active production environments and schedules. A real product order was imported into the model and the simulation result was compared with the actual results. For a two-hour run time of actual production, measurements were taken, resulting in the calculated time per station as per table 2.

The deviation between simulation and actual numbers was negligible. For one of the stations, it was large, but acceptable as it was small orders. Improvements in that station were targeted for the next phase of improvements.

Having validated the accuracy of the simulation, the team determined that strategy one was ideal. In actual results measured, strategy one hit the forecasted goals of 51,186 units.

This study improved the throughput and developed a simulation model that can be used with all the future order combinations.

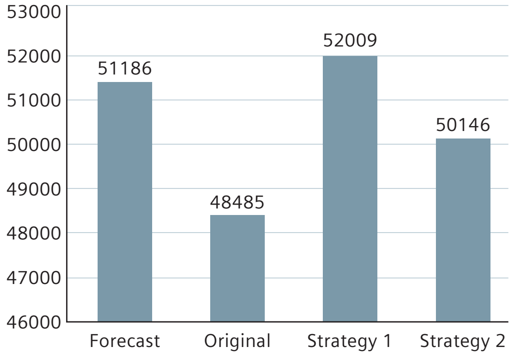


Figure 5: Capacity/throughput simulation results.

Run time: 2 hours

					Reality	Simulation
Position	Frame number	ASE	Worker	CT(min)	Output number	Output number
M1	6	A5E32947774	1	5.71	21	21
M2	6	A5E32986969	2	1.875	32	32
M3	6	A5E32947829	2	1.36	44	40
M4	6	A5E36066425	2	1.428	42	34
M5	6	A5E32947785	1	2.608	23	22

Table 2: Actual results of wave station study.

Original

Strategy 1

Strategy 2

Figure 6: Utilization simulation results.

Logistics material flow simulation

The next study is the simulation of material delivery flows for the "water spider" position. For this next study, one needs to first understand the concept of the water spider. There are different ways to handle parts and materials when organizing a factory floor, and one interesting option that is part of the lean manufacturing methodology is the water spider. The water spider is a term that refers to a specific person whose main job is to make sure that materials are supplied where they are needed. Although this is mainly a material replenishment position, it offers a bit more flexibility, and some additional benefits if well-implemented. The rationale behind having such a person is to allow the rest of the personnel to devote their full attention to tasks that add value to the process. This also highlights how much transportation waste and inefficiency exists in the process by isolating it all into one or more positions.

To the untrained eye, a water spider might look like a free floater that does a variety of tasks in addition to making sure materials are properly stocked everywhere. It's easy to get the misleading feeling this is a bit of a chaotic role, but this could not be further from the truth. Although the water spider needs to make sure the production flow is uninterrupted and unobstructed, they should also follow a standardized process. The job of the water spider is not to increase variability by constantly improvising and being excessively flexible, but to minimize variation for everybody else on the production floor or within the process. Simply, it makes everybody's job more value-added, and therefore easier to standardize and optimize.[5]

As the water spider's rounds are time-sensitive, and timing should be part of their standardization, they might sometimes end up making too many empty rounds. This is an inefficiency that is often easy to overlook, but it should be addressed. Of course, as the water spider's main role is to keep the whole process ticking, a small amount of inefficiency is to be expected. Remember, they are trying to optimize the system, not their own time, so that will naturally lead to some inefficiency. It can be acceptable as long as the water spider manages to help boost the efficiency of the whole operation.[5]

Using Plant Simulation software, the layout, VSM and various inputs were measured and entered in order to produce a model that could be used to test multiple scenarios. A specific production area was selected (G120 AA). In figure 7, the team outlined the parameters for the study. The expected output was anticipated to help management determine the headcount needed and various metrics related to walking distance, capacity requirements, workload analysis and whether the replenishment schedule could meet the production forecast.

Request input

1. FGs product PN
2. BOM
3. Monthly demand – WH, base on 2019.06 new forecast
4. Lot size – 8
5. C/T, C/O
6. Storage capacity in line side rack & pcs in one container
7. Layout (distance in SuMa, line side rack and between of them)
8. Working time for each step

Approach

- Summary and input product data to build up simulation model
- Verify simulation model in real production cells
- Make experiment to get improve measure (frequency, work load, route)

Expect achievement

1. HC Qty & walking distance of water spider
2. Work load chart
3. Capacity requirement for trolley
4. Max. replenishment LT can meet production running

Figure 7: Water spider analysis parameters and approach.

The management target was to set up a re-usable model to calculate and decide the number of resources to replenish material from the department supermarket to the production cell. The key to the study was the output of headcount demands based on the daily production forecast.

Figure 8 illustrates the value stream map as depicted in the simulation software. It should be noted that since Plant Simulation includes logistics and value stream objects that can be configured, simply making them unrestricted within the simulation value stream map allows tremendous flexibility for the software and user.

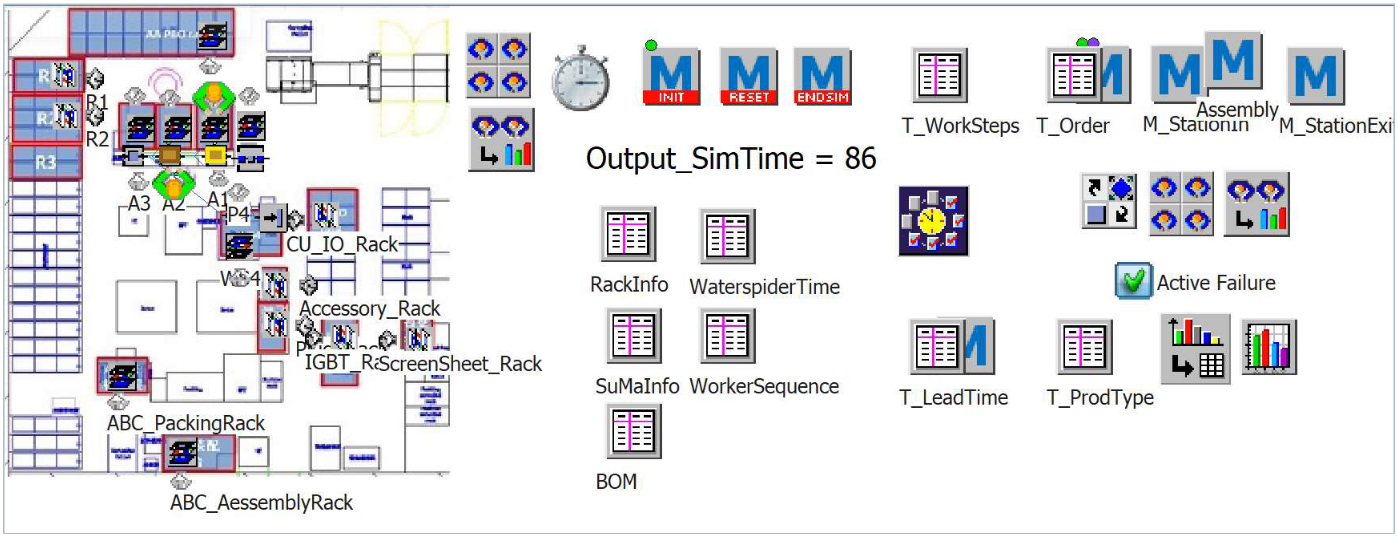


Figure 8: Water spider VSM for G120AA production area

Nine experiments were performed in the simulator; variances in layout, distance, the quantity of one container, work sequence, etc. The results of the experiments are shown in figure 9 below.

The outcome resulted in experiment 6 as the ideal work sequence and layout while minimizing the total distance traveled, but also ensuring that the production forecast was met. With the production runs in the study, a 25 percent improvement was identified. Also, it is key to note this model is now used during every production planning session to minimize the number of water spider resources and ensure their work sequence and route are optimized to meet the production forecast while minimizing waste.

Results

1.HC Qty & walking distance of water spider.

2.Work load chart.

3.Capacity requirement for trolley.

4.Max. replenishment LT can meet production running.

	root.WaterspiderTime[2,1]	root.drain.statnumont
Exp 1	10:00.0000	87
Exp 2	20:00.0000	87
Exp 3	30:00.0000	86
Exp 4	40:00.0000	86
Exp 5	50:00.0000	85
Exp 6	1:00:00.0000	85
Exp 7	1:10:00.0000	78
Exp 8	1:20:00.0000	68
Exp 9	1:30:00.0000	61

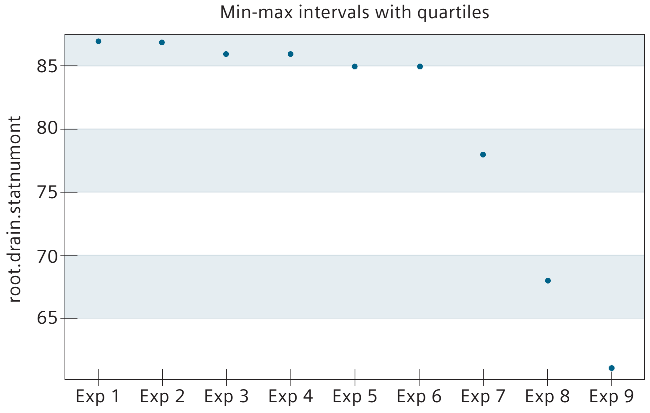
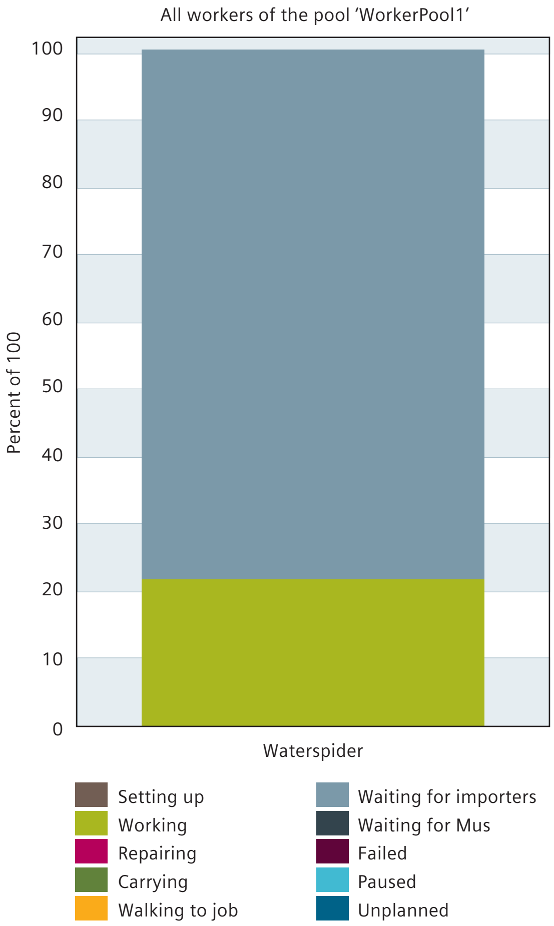


Figure 9: Water spider experiments results.

UV coating robot automation simulation

An automated UV coating cell has been deployed at SNC, as depicted in figure 10. This cell was set up based on the recommendation by the vendor and some initial layout and MS Excel based time studies. As this is a single cell, optimizing single processes is done using Process Simulate software. Process Simulate is a digital manufacturing solution for process verification in a 3D environment. Using Process Simulate enables manufacturing organizations to virtually validate manufacturing concepts upfront, which may include work sequencing within a cell, robot simulation, cobot simulation and human simulation and ergonomics analysis.

With the production runs in the study, a 25 percent improvement was identified.



Simulation for this study was done with Process Simulate utilizing 2D and 3D visualizations created in Siemens' NX CAD software. Any CAD software that can output JT format (as described earlier) is supported.

The first step in creating the simulation was to ensure we identify all the parts of the cell. As shown in figure 10, the related positions of human workers, their specific orientation and movement of the robot are modeled.

Three main modeling activities were necessary to simulate this complex environment:

1. The robot movement.
2. The human resource movement.
3. The sequence and time simulation based on virtually commissioning the robot program (recipe).

The robot used to take the readied part from one of the two tables and insert it into the sprayer machine was modeled based on information provided by the robot vendor. The program (recipe) can be created directly in the software or imported into the simulation model so the actual movement can be simulated. A sample of how this would appear is described in figure 11.

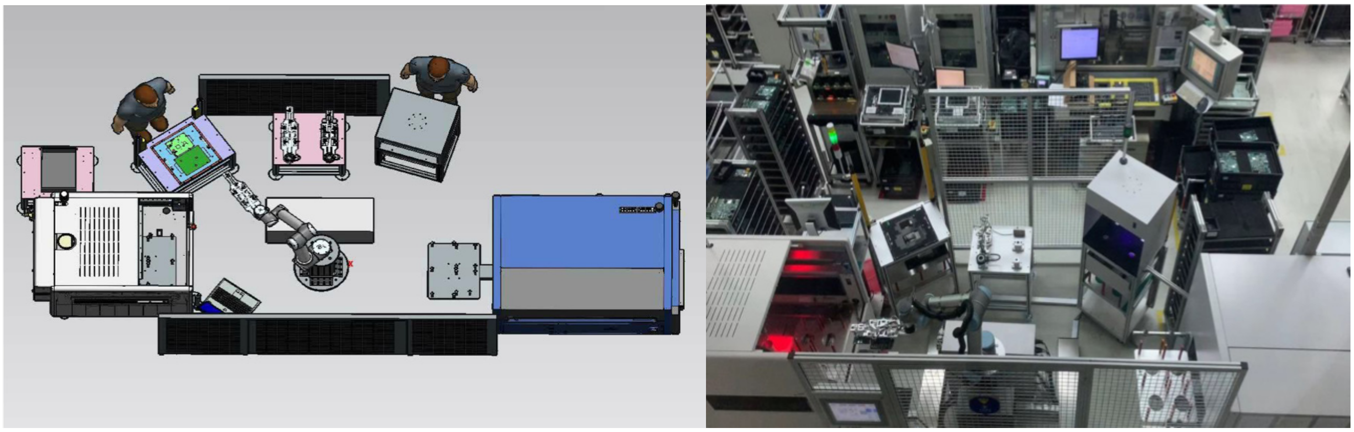


Figure 10: UV cell simulation model.

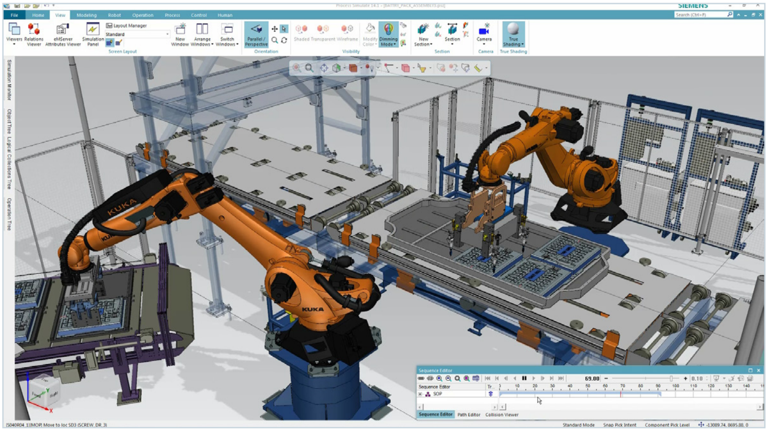


Figure 11

Human movement modeling is also important since it may be possible to optimize the efficiency and speed of factors that lead to wasted movement while ensuring actions are done safely within the proximity of the cobot, as shown in figure 12.

Finally, the robotic program can be simulated, modified and commissioned. Figure 13 describes how that was done at SNC for the UV coating robot loader.

At SNC, the robot was simulated along with human worker actions and positions, and the model was defined to validate and simulate production on a regular basis during production planning. SNC realized the following benefits after putting this manufacturing simulation process in place:

- Reduced engineering efforts
- Less debugging
- Shorter commissioning time

35 percent improved line performance

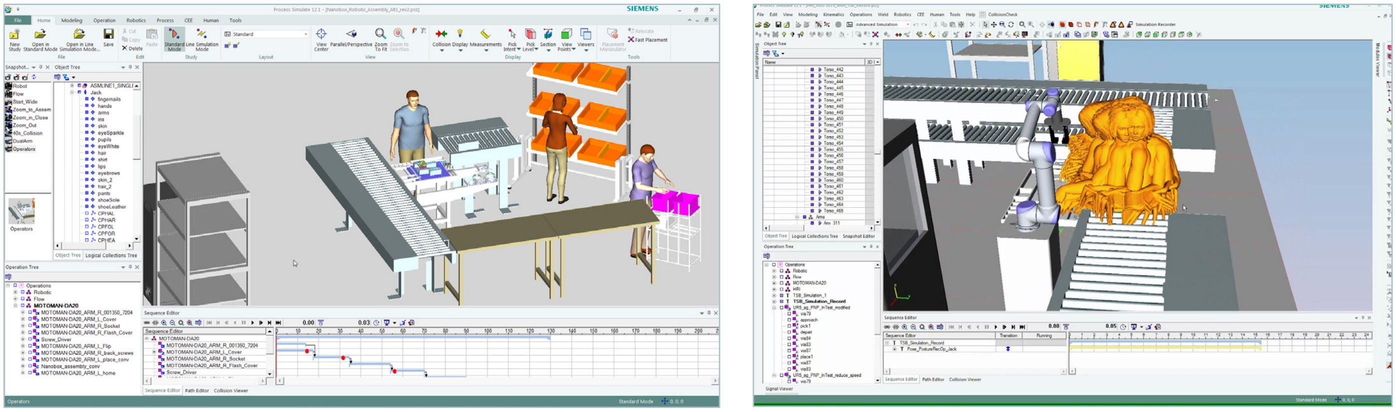


Figure 12

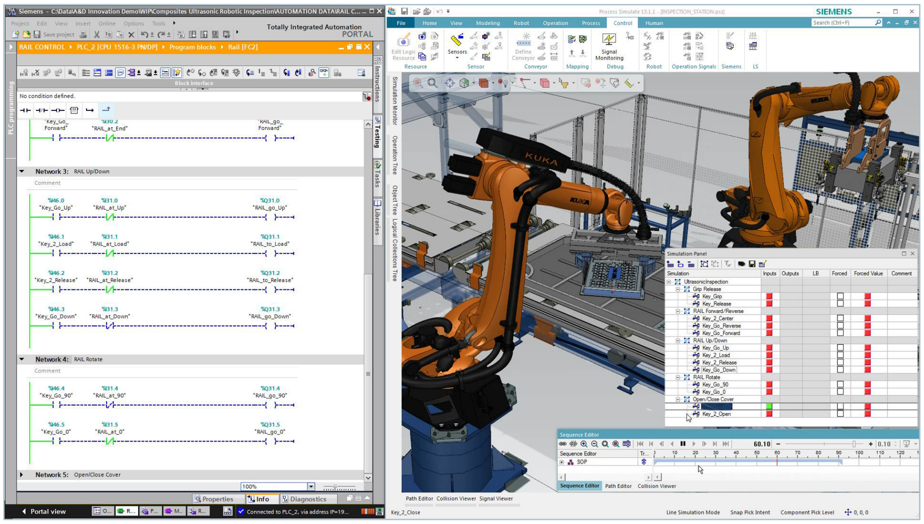


Figure 13

Conclusion

This paper describes the design and implementation of several manufacturing simulation use cases at Siemens Numerical Controls Ltd., an electronics assembly factory in Nanjing, China. Based on initial bottleneck studies performed at the factory, three main areas were identified as opportunities for improvement; 1) Capacity simulation of wave soldering machines, 2) Logistics material flow simulation and 3) UV coating robot automation. The model developed and tested for the wave soldering machines is now used in production planning and forecasting as well as their daily planning meetings to better order the sequence and product assignment. The water spider analysis project allowed production planners and manufacturing engineers to determine the optimal number of water spider resources, their work sequence and total path traveled to ensure that production forecasts are met. For the period of the case study, the team recorded a 25 percent improvement. Finally, we described by simulating at the cell level, robot movement and programming simulation combined with human movement and ergonomics simulation facilitated a 35 percent improvement in line performance.

Manufacturing simulation is no longer reserved only for specialized engineering and industrial organizations. Automotive, aerospace and large machinery companies are not the only benefactors of manufacturing simulation. Based on this paper, we can clearly see there are benefits to electronics manufacturing companies, especially for optimizing production throughput and costs.

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