# AN INTEGRATED SIMULATION AND OPERATION COSTING APPROACH TO ASSESS ORDERS PRODUCTION COSTS: A REAL APPLICATION 

Antonio Avai ${ }^{(\mathrm{a})}$, Marzio Sorlini ${ }^{(\mathrm{b})}$,<br>${ }^{(a)}$ Technology Transfer System s.r.l., Milano, Italy<br>${ }^{(b)}$ SUPSI-ICIMSI, Manno, Switzerland<br>${ }^{(a)}$ avai@ttsnetwork.com, ${ }^{(b)}$ marzio.sorlini@ supsi.ch,


#### Abstract

This paper describes a new and integrated approach for providing an accurate and reliable estimation of work orders production costs meant to ease customers' bid preparation. For many small and medium third-party service providers, facing almost homogeneous product portfolio and a finite number of production lines, is really worthwhile to provide a precise production costs estimation as a basis for further decisions to accept or reject an order. Because of information on processing times are tough to be estimated in such companies, the idea was to integrate the discrete event simulation technique, providing accurate and reliable process evaluations, with the operation costing technique to assess orders production costs. A new tool called "cost simulator" was developed based on this integrated approach and it was validated on a real industrial case in the wooden painting sector.


Keywords: discrete event simulation, operation costing, order cost, production management

## 1. INTRODUCTION

Discrete event simulation is widely used to model production lines (Roser et al. 2003) and to analyze and optimize their overall performances as well as their behaviour (Boer et al. 1993), (Voorhorst et al. 2007).

Cost analysis integrated with simulation technique has been mainly investigated to support decisions during the process design phase for instances to assess the net present value (Murray et al. 2000), to coordinate manufacturing investment with marketing and product design to jointly achieve optimal product line solutions (Michalek et al. 2005), to find an optimal production control (Gahagan et al. 2005) or to assess the efficiency of business process reengineering (Wang et al. 2001). Such an approach has been applied also to the logistic area, for example to compare transportation costs in a cooperative and a non-cooperative context (Diaz et al. 2003) or to evaluate the operational costs and performances associated with liner shipping (McLean 2008). While Von Beck has linked Activity Based Costing ( ABC ) and discrete event simulation to provide cost estimation in manufacturing environments to
support more informed operational and strategic decisions (Von Beck et al. 2000).

The operation costing technique is more suitable for third-party services because it represents a good compromise between reliability of forecasted data, inputs monitoring and computation complexity, especially for companies with almost homogeneous product portfolio and a finite number of production lines (Howell 1987), (Drury 2007).

This paper describes a new integrated approach combining the discrete event simulation with operation costing to assess work order production costs for bid preparation. This approach was also applied on a real case in the wooden painting sector

The next two paragraphs ( $\S 2$ and $\S 3$ ) shortly report the problem and the objectives of the work. After, a description of the addressed production system (§4) is given, while paragraph 5 presents the overall approach and the resulting tool. In paragraph 6 results and sensitivity analysis are described.

## 2. PROBLEM DESCRIPTION

The main challenge of the work was to provide a good and reliable estimation of work orders production costs meant to easily and precisely prepare customers' bids.

The small company facing such a problem is a third-party service provider running its business in painting wooden components mainly for furniture, such as doorways for kitchen, bathroom and living room, drawers, window frames, etc.. It receives materials (unpainted wooden boards) from its customers for workmanship only. The finished wooden products are then returned to the contractor.


Fig. 1 Some finished products

This company can paint a broad range of wooden products changing in sizes, geometry and typology, also starting 15-20 new products each year.

Each order, coming from the customers, is formed by different products, varying in:

- Product typology: doorways, drawers, window frames, etc..
- Product sizes: the length as well as the width can range between 50 mm up to 1300 mm ;
- Quantity of each product.
- Processing types to be performed to obtain products complying with customer requirements. 9 processing types are offered by the company, each one with some variants amounting to 30 different process sequences.

This wide multiplicity of components, processing types and orders makes the bid preparation a real challenge. The main problems are the order estimation of: indirect costs, lead time (always influenced by many factors), time and number of personnel involved. To get a good estimation of time and resources utilization is fundamental to prepare a reliable and accurate customer bid.

Looking at the last balance sheet of this company, $46 \%$ of costs, leaving aside raw materials (that weight for over $40 \%$ ), are due to manpower involved in the production department, making its correct ascription a conditio sine qua non for a good bid estimation.

## 3. OBJECTIVE OF THE STUDY

The objective was to identify a new approach able to provide an accurate and reliable estimation of work orders production costs meant to ease customers' bid preparation and/or to verify their feasibility. Price is a critical success factor for small third-party service providers: high prices discourage customers, while too low prices abate company profitability. It's really worthwhile to be able to provide a precise production costs estimation as a basis for further decisions to accept or reject an order.

This approach, called cost simulator, integrates discrete event simulation with the operation costing, coupling accurate in-depth information on production times and resources with a precise estimation of production costs. Combining these two techniques, it is possible:

- To get accurate cost estimation, even concerning new products.
- To highlight production system bottlenecks and to suggest ways to manage them, thanks to simulation.
- To support awareness creation: both the preliminary analyses performed in order to design the tool and its constant usage and update drive the company towards a formalized representation of internal capabilities and resources.

This approach is useful both for salesmen during the bid preparation as well as for the production responsible to improve production performances.

## 4. THE PRODUCTION SYSTEM

The production flow of the analyzed small company starts from the warehouse, where components (wooden boards), received from customers, are stocked, goes through the four production departments and finishes in the packaging department, where products are prepared to be delivered.

Each department is equipped with a plant performing peculiar processes. Thanks to this kind of organization, the company is able to work a broad spectrum of wooden products. A more detailed description of the five departments follows:

1. The dyeing department: it's the starting point of the working process. Raw component is dyed and prepared for next processing by means of a dyeing plant with 2 rotary machines with forced dyeing and a warm air ventilation oven for drying the wooden elements.
2. The lacquering department: this plant is able to lacquer flat wooden elements of various dimensions and types as well as to apply transparent finishing on thick pieces.
3. The painting department: elements, showing particular shapes (curved doors, bases and boards), are painted manually using the spraying "Airmix" technology.
4. The finishing department: this automatic plant can produce several finishing in high quantity and quality. It is equipped with an innovative spraying system with piece-dimension reading (meant to reduce over-spraying) and with a product recovery carpet (meant to reduce the impact of emissions in atmosphere).
5. The packaging and tinning department: the finished components are firstly checked for quality control and then packaged with a packaging unit equipped with an automatic paper-box and labelling device.

The working sequence depends on customer requirements and component materials, while component shape has an influence on plant selection. For instance, the painting process can be performed in two departments: flat components are painted in the finishing department while curved ones are painted manually in the painting department. Generally speaking, a component is dyed one or two times, then it's finished and packaged.

Currently, 28 workers are employed full time in the five departments and 5 foremen staff the 5 plants. The main tasks of each foreman are to continuously monitor the plant running operations, to prepare the raw materials for painting devices and, sometimes, to help other workers in making their job on the plant.

The other 23 employees can turn between the different plants based on the production needs performing the following tasks:

- Loading components on the conveyor system and unload finished ones.
- Performing manual operations such as brushing ash doors.
- Cleaning the plant at least once a day.

The number of workers involved in the loading and unloading processes depends on the components weight and length. The heavier and/or longer is a component, the higher is the number of involved workers. Anyway, due to space constraints, a maximum of 3 workers can load or unload at the same time. Furthermore, the load and unload processes in the same plant happen in a spot way: workers perform loading until the plant is full of components and unloading just at the end of the process. In the meantime the plant works automatically and components go across the plant 2 or 3 times in order to undergo many hands of painting, or front and back painting. During this period, the loading team can be allocated to another plant. When the first worked component is available to be unloaded, some workers have to be re-allocated to this plat to start the unloading process and, at the same time, another team re-starts loading components to be painted.

Some other manual processes are made in the same way. In this case the total number of involved workers can range between 2 and 7 .

It's easily understandable how the estimation of personnel saturation is very tough but, at the same time, how it heavily influences the production costs. Furthermore, an efficient resource allocation (for example re-allocation between loading and unloading on the same plant) can influence production costs.

## 5. THE COST SIMULATOR

The cost simulator goal is to calculate reliable and accurate cost estimation of work orders. It's based on the integration between discrete event simulation and operation costing techniques. It is composed by two different models:

- A Cost Model containing the cost information needed to get production cost estimations.
- A Simulation Model, representing all the production processes.

The Simulation Model simulates a work order production flow. Resulting data, dealing with timing and resources utilization, are inputs of the Cost Model in order to estimate costs.

The next two paragraphs report a detailed description of the cost and Simulation Models.

### 5.1. The Cost Model

Providing reliable cost estimations for assessing a work order production cost is the main goal of the Cost Model.

In order to perform an estimation of production costs, traditional cost accounting procedures (Howell 1987), (Drury 2007) suggest a distinction between direct and indirect costs. The overall production cost for a work order is equal to the sum between costs directly and unambiguously chargeable to the given order and a percentage of costs that are not directly accountable to the particular order. In the here described scenario, given that the supplier holds the ownership of wooden boards, dye, solvents and similar products are the only direct costs. The amount of dye for each work order depends on the overall dyed area.

On the other hand, indirect costs estimation appears to be difficult due to the above described peculiarities.

An operation costing approach has been adopted: the only direct (dye) costs are univocally charged to a given work order, while indirect costs are (almost causally, but proportionally) allocated using suitable dimensions. Third party wooden painting production characteristics are consistent with main applicability indications of operation costing (Zuk 1990), (Drury 2007): products with strong similarities yet differentiated in some forms from each other, batch production and variable but discrete production systems.

The Simulation Model gives an estimation of production times and workforce time per work order; therefore indirect costs were split into two groups: workforce costs and other production costs, with the goal to reach an estimation of unitary (hourly) values for each of the two categories. In fact, each work order is processed in different departments and, on the other hand, each worker is able to operate in more than one department.

Average hourly workforce cost was valued as a ratio between the overall annual production workforce cost (derived from the last final balance) and the annual amount of production hours. Only the 23 ordinary workers salaries were taken into account for this calculation, while the salaries of (5) foremen appointed to supervise each department were left aside.

Average hourly production cost for each department was calculated in a more complex way. Two typologies of costs were defined:

- IFO_DFP (Indirect for the Order, Direct for the Production unit): costs directly accountable for the 5 production departments. The identified classes are:
(a) The 5 foremen salaries.
(b) Equipment (and pertinent components) depreciation.
(c) Equipment leasing/rental and maintenance.
(d) Equipment leasing/rental.
- IFO_IFP (Indirect for the Order, Indirect for the Production unit). They were:
(a) Water, energy, gas, compressed air and other costs clearly ascribable to existing equipment and calculated thanks to a pro-quota distribution among the 5 departments.
(b) Production shed rental, shed heating, training costs, consumables, and other costs partially ascribable to the production activity.
(c) Overheads.

Going from (a) to (c), the causality of the ascription of the costs to each equipment decreases.

Each cost, belonging to IFO_IFP(a) category, was ascribed to a given department/equipment using a proper ascription driver. For example, the energy cost per hour of equipment was calculated as the annual cost for all the equipments energy multiplied by an "equipment energy weight". It is the ratio between the equipment maximum power multiplied by its annual running time and the sum of the maximum power of each plant multiplied by each plant annual running time.

The overall amount of workforce working hours was selected as a driver for all the IFO_IFP(b) costs. The amount obtained dividing the overall IFO_IFP(b) costs for the overall amount of workforce working hours was added to the workforce hourly cost. This ascription derives from the observation that IFO_IFP(b) costs are strictly related to the number of working hours. This choice drove the authors to consider IFO_IFP(b) unitary costs as an additional charge for the workforce hourly cost.

The overall number of equipment running hours is, finally, the driver adopted for IFO_IFP(c) costs.

Summing up, the cost for a given work order derives from:

$$
\begin{aligned}
& C(W O(i))=D C(i)+W H C * W W H(i)+\sum_{j=1}^{5} P H C(j) * P R H(j, i) \\
& C(W O(i))=\text { Work Order }(i) \text { Overall cost } \\
& \begin{array}{l}
D C(i)=\text { Work Order }(i) \text { Direct Costs }= \\
\quad=\text { Required Dye Volumes } * \text { Dye cost per volume unit } \\
\text { WHC }=\text { Workforce Hourly Cost }= \\
\quad=\frac{(\text { Workforce Annual Cost }+ \text { IFO_IFP }(b))}{\text { Workforce Annual Working Hours }}
\end{array}
\end{aligned}
$$

$W W H(i)=$ Workfoce Working Hours for Work Order (i)
as calculated by the simulation model
$j=1 . . .5=$ equipments - departments
PHC $(j)=$ Production Hourly Cost for equip. $j=$
$=I F O_{-} D F P(j)+I F O_{-} I F P(a)(j)+I F O_{-} I F P(c)(j)$
$\operatorname{PRH}(j, i)=$ Production Running Hours of equip.(j) and
for Work $\operatorname{Order}(i)$ as calculated by the simulation model
The Cost Model is MS-Excel-based and interacts with an already existent internal accounting platform adopted by the company, automatically importing and
re-grouping required inputs. The company account manager validated the above described Cost Model.

### 5.2. The Simulation Model

The main goal of the Simulation Model is to assess processing times needed to work a customer order. So it has to reproduce all the material production flow.

For this real application, it was decided to simulate only 3 departments:

1. The dyeing department.
2. The finishing department.
3. The packaging department.

In fact, examining all the work orders of the last 6 months, and interviewing the company team manager, it comes up that about $70 \%-80 \%$ of orders are worked only in these two departments:

The first step was to analyse and to map all the production processes involved in working an order, from its reception to its delivery, considering also the reworked process. However, the defectiveness rate is very low, so the rework process was not included in the model.

In contemporary, a deep analysis on the orders was carried on with the objective to identify a set of pilot orders that will be used to test and validate the Simulation Model as well as the cost simulator.

Afterwards, the two departments along with the packaging one were analyzed in a deeper way. All the technical and operational data were gathered and a particular attention was kept to collect information on work orders management. A list of all the feasible operations for every plant was defined and, for each one, some key parameters were fixed such as: conveyor belt velocity, number of workers, number of complete turns in a plant, etc. All these data were coded and put in an Excel file which is the input file driving the Simulation Model.

All the examined plants are loaded manually and, because of its impacts on the system performances, the loading process was analyzed deeply. Workers involved in this process have to comply with some rules and constraints but, at the same time, they should put on the conveyor belt as many components as possible in order to maximize the system throughput. For instance, it's very fundamental to leave some room between close components loaded on to the conveyor belt to assure a uniform paint layout on each part and reduce the risk of future rework operations. Currently the loading process is made by workers without any kind of support: neither defined and written procedures nor software tools to optimize components placement are available. Workers decide the loading sequence time by time based on their past experiences, on how all the components have been piled and avoiding to mix different orders.

In the analysis phase, the loading process was formalized and coded in a computer model with the help of Excel. The goal was not to find out the optimum loading solution considering a work order, but a feasible
sequence complying with the actual rules and technical constraints. In the Excel model, all the main constraints were defined and, by means of some formulas reflecting the actual rules, a loading sequence is calculated starting from any kind of work order. Furthermore it was defined a key indicator called "area efficiency" meant to measure the ratio between the square meters taken by components loaded on the conveyor belt (the brown area in Fig. 2) and the available square meters (the yellow area in Fig. 2). Likely, the system throughput should increase, raising the value of this indicator. So a first level of optimization was implemented in this model selecting the solution with the best key indicator value.


Fig. 2 The component placement in the loading process
The Simulation Model was developed in Arena® (Kelton et al. 2007). At the beginning of each run, and for every department, the model reads the input file, in Excel format, with the following information:

1. The components loading sequence.

The machining type to be performed.
The operational data.
The number of workers needed for each manual job, especially for the loading and unloading task.


Fig. 3 The finishing department layout
The model simulates all the working processes needed to paint, finish and packaging customer orders recording the time frame in which workers have been busy. At the end of the simulation, the model records the following data in an output file in Excel format:

1. The total number of man hours taken to perform each manual task in each work center.
2. The total number of man hours taken to work the order in each plant.

The Simulation Model also keeps into consideration the set up time of each plant when the responsible prepares the raw materials (dyes, solvents, etc.) to paint or finish the components and makes all the
procedures to clean the spraying machines and/or change some tools.

From the Cost Model, the Workforce Hourly Cost (WHC) and each Production Hourly Cost for every equipment ( $\mathrm{PHC}(\mathrm{j})$ ) are imported in the output file in order to calculate the production costs of the simulated order (Work Order Overall Cost).

Furthermore, the model generates an output report with some key indicators such as:

1. The average hourly throughput of each plant measured in square meters per hour.
2. The drying oven saturation measured as the ratio between the square meters occupied by components and the total square meters available in the oven.
3. The average lead time measured in second.
4. The average Work-In-Progress measured in square meters.

Such a report provides the foundation to make result analysis to achieve some system improvements. In addition, using the information generated by the simulation about the time in which human resources have been busy, an allocation plan can be identified in advance. As mentioned above, an efficient allocation plan can help in saving money and time.

## 6. VALIDATION AND RESULTS ANALYSIS

The validation is the process of determining whether a simulation model is an accurate representation of the system for the particular objectives of the study (Law 2001). This process usually takes a long time and it's not as simple as it might appear, thus it was decided to carry on the validity assessment only with the help of process experts from company.

The validation method was as following: first the simulation model was tested comparing the flow time, (i.e. the total time taken by a work order in a department to be completed) against some historical data; then the manpower time was validated.

During the first test, the simulation model was refined few times to add minor details influencing the results, and, in the end, it reached a high level of accuracy. The difference between simulation and historical data was about $5 \%$, which is adequate for this kind of project.

The manpower time comparison was more complicated because simulation results were not so close to the historical data as it was expected. Further investigations were made by direct observations: the simulation model estimations were accurate. The actual method to assess workers saturations, based only on data recorded by the same workers, was often not correct, thus generating bad estimations.

### 6.1. Sensitivity analysis

Once the validation phase was ended up, the Simulation Model was also used to estimate the impact of some key factors on the system throughput. Such estimation was
performed only for the finishing department because it has the highest annual utilization rate.

A sensitivity analysis was carried on the following two key factors:

1. Area efficiency during the component loading process.
2. Plant saturation.

The close relationship between these two factors and the throughput is already known, but the scope was to quantify the effect. The results are described in the next two subparagraphs.

### 6.1.1. Area Efficiency analysis

The main goal of this analysis was to evaluate the impact of the components placement on the plant performances.

As already mentioned, components have to be loaded onto the plant complying with some rules, constraints and, at the same time, trying to fill in the available loading area as much as possible. The more square meters are painted per hour, the higher is the productivity.

This sensitivity analysis was performed on a set of hypothetical orders composed by only one product with different dimensions, in order to get different values for the key indicator "area efficiency". As already said, it measures the ratio between the painted square meters and the ones available on the conveyor belt. The considered set is composed by 50 samples. They are all worked with the same process and the total number of square meters to be painted is similar and great enough to avoid the effect of the warm up period in the simulation. Furthermore, it was assumed that the loading time is not related to the number of components to be placed on the conveyor belt each time, but only to the components length. It means loading 2 or 3 components with the same length takes the same time. It's not such a stringent assumption, also because it actually happens in the real production process, where the number of people charged of loading components, depends on components length and weight.

From a first analysis, the area efficiency indicator value is directly related with the component width, assuming its length as fixed (see Fig. 4). In other words, increasing the components square meters, the area efficiency indicator and the system throughput raise up.


Fig. 4 Area efficiency vs. component width

But this direct relation is not valid any longer when considering components where both dimensions are different. The chart in Fig. 5 shows the average area efficiency value for each class of components (a class is a collection of components with the same length but with different widths).


Fig. 5 Area efficiency vs. components classes
The simulation results confirm the close relationship between the area efficiency and the system throughput. The correlation value is about 0.95 , a quite high value. The linear regression is as follows:

Throughput $=219.36 *$ area efficiency -11.78
However, carefully analyzing the results, for instance looking at indicator values close to $62 \%$ (see chart in Fig. 6), the productivity ranges from 119 to 138 square meters per hour. It is due to the different length of the worked components. A new linear regression was calculated keeping into consideration also this factor and the formula is as follows:

Throughput $=218.16 *$ ae $+0.008 * \mathrm{cl}-13.01$
ae= area efficiency
$\mathrm{cl}=$ component length


Fig. 6 Throughput vs. area efficiency

The graph in Fig. 7 compares the throughput generated by the simulation and the value calculated with the linear regression.


Fig. 7 Area efficiency vs. throughput
To be statistically sure about this result, a validation hypothesis test was performed with the null hypothesis being the two parameters (area efficiency and component length) have no effects on the throughput (Chung, 2004). For a two-sides test at a common level of significance $\alpha=0.05$, the critical values from the $t$ distribution are -2.017 and 2.017. The calculated $t$ for area efficiency and component length are respectively 31.3 and 10.7 . They both exceed the above values and so the null hypothesis is rejected. Area efficiency and component length have an impact on system performances.

This analysis highlights how an efficient loading sequence can increase the plant throughput: moving from $50 \%$ to $60 \%$ of area efficiency means to gain about $20 \%$ of productivity.

### 6.1.2. Plant saturation analysis

Generally, components go across the finishing plant 2 or 3 times. Clearly this plant has a fixed capacity and if the square meters of an order exceed its capacity, the work order has to be split into smaller batches whose capacity can fill up the plant. It means that while the first part is unloaded, the second part of the same order can be loaded into the plant.

Looking at the different components types and dimensions worked in this plant, its capacity, under normal working conditions, can range between 300 and 500 square meters.

The main goal of this analysis was to evaluate the impact of plant saturation on the hourly throughput. In order to keep the analysis as understandable as possible, it was assumed to work orders with only one component but the total square meters to be painted changes in each trial. The area efficiency value is close to $70 \%$ and the processing type requires working both front and back part, meaning to cross all the plant 2 times.

As expected, there is a close relationship between plant saturation and system productivity: the correlation
value is near 1 . The throughput is sensible to the order quantity that's the smaller the quantity to be worked, the lower the hourly productivity. It can cut down up to $19 \%$ considering a small order (see Fig. 8). But also considering very big orders, with 2 days of lead time, the productivity value can decrease from $3 \%$ to $6 \%$.


Fig. 8 Throughput vs. plant saturation
These results suggest the idea to try working with the plant always full of pieces, joining different work orders, when possible, in order to keep the plant as saturated as possible.

## 7. CONCLUSION

The cost simulator, based on the integration between the simulation and the operation costing models, was able to provide more accurate production costs for historical orders than the existent method merely based on past experiences. Furthermore, this calculation takes few minutes, even for big orders.

The Simulation Model can be used also to define feasible resource allocation plans as well as to find out bottlenecks or critical aspects. For the analyzed company, the loading process is very critical because it has a strong impact on the throughput.

Lesson learnt is that the cost simulator adds real values when it's very hard to estimate orders costs due to their big variability and the evaluation of production times and resources utilization is difficult. These topics are quite common in many small and medium thirdparty services.

Next steps will be the completion of the Simulation Model to represent all the departments in the shop floor and to improve the integration between the cost simulator and the existing software tools meant to make easier for the account manager to add new costs and correctly map them in the Cost Model.

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## AUTHORS BIOGRAPHY

Antonio Avai is a partner and technical director of Technology Transfer System, an IT company located in Milan. He has managed research programs with focus on methodologies and leading information technologies to support all the life cycle of manufacturing processes. He has more than 15 years of experience in discrete event simulation and its integration with other software tools and technologies, and has authored several papers on these topics.

Marzio Sorlini graduated in Management Engineering at Politecnico di Milano with major in strategy and innovation management, he worked as junior researcher at ITIA (Institute of Industrial Technologies and Automation) being engaged in (5th and 6th FP) EUfunded projects on innovation management, decision support systems and innovative cost accounting methods for integrated product-service solutions development. He's currently employed at SUSPI-DTI (University of Applied Sciences and Arts of Southern Switzerland - Department of Innovative Technologies) and co-operates with Technology Transfer System.

