Using simulation for facility design: A case study

Andrew Greasley *

Aston Business School, Aston University, Aston Triangle, Birmingham B4 7ET, UK

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A B S T R A C T
A discrete event simulation model was developed and used to estimate the storage area required for a proposed overseas textile manufacturing facility. It was found that the simulation was able to achieve this because of its ability to both store attribute values and to show queuing levels at an individual product level. It was also found that the process of undertaking the simulation project initiated useful discussions regarding the operation of the facility. Discrete event simulation is shown to be much more than an exercise in quantitative analysis of results and an important task of the simulation project manager is to initiate a debate among decision makers regarding the assumptions of how the system operates.

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1. Introduction

A variety of computer software can be utilised in the task of manufacturing and service facility design. For example, there is widespread use of spreadsheets to conduct investment appraisal of proposed equipment and capacity planning calculations. However, these calculations are static in nature in that they have limited ability to allow changes in system behaviour to be analysed as a function of time. Discrete event simulation is concerned with the modelling of systems that can be represented by a series of events. The simulation describes each individual event, moving from one to the next as time progresses. When constructing a discrete event simulation the system being simulated is seen as consisting of a number of entities (e.g. products, people) which have a number of attributes (e.g. product type, time in system). An entity may consume work in the form of people or a machine, termed a resource. The amount and timing of resource availability may be specified by the model user. Entities may wait in a queue if a resource is not available when required. Early discrete event simulation systems generated reports of system performance, but advances in software and hardware allowed the development of animation capabilities. When combined with the ability to interact with the model this technique became known as visual interactive simulation (VIS). Most simulation modelling software is now implemented using graphical user interfaces employing objects or icons that are placed on the screen to produce a model. These are often referred to as visual interactive modelling (VIM) systems. Because of the use of simulation in the context of business process re-engineering (BPR) and of other process-based change methods the technique is also referred to as business process simulation (BPS).

2. Methodology

A case-based research methodology was chosen with the aim to provide an example of practice and test the proposition that discrete event simulation is an appropriate tool in the context of facility design and to outline the full quantitative and
qualitative benefits of conducting a simulation study in this context. In this study the author acted in a consultancy role and undertook both the process of the simulation study and the construction of the simulation model itself. This might imply an action research methodology and indeed in practice action research and case study research are similar in many of their procedures and both are associated with the same research paradigm of phenomenology [5]. However, in this case the purposes of the intervention from the client perspective was to provide data from the simulation for an organisational decision and was not concerned with the author’s research interest in simulation use. Thus there is a separation between the outcome of the consultancy and the outcome of the research analysis. Action research is associated with the mutual control by the researcher and client of the research and analysis of results. In addition the final action plan to be implemented is usually the client’s responsibility, supported by the researcher and the research report is often published jointly by the researcher and client [5]. In terms of the case study approach Gummesson [11] states that it has the advantage of providing an holistic view of a process. According to a holistic view the whole is not identical to the sum of its parts and so the whole can only be understood by treating it as the central object of study. Also case studies are of particular value in applied social sciences where research often aims to provide practitioners with tools. Although a single-site study has obvious limitations with respect to the generalisability of the findings, the case is not aimed at being representative, but rather exemplary, thus the researcher does not need to assume that what is observed is truly representative of all similar situations [18]. Collection of data such as process durations, task allocations and process relationships for the study was undertaken by the author and employees of the organisation in order to construct the process maps and simulation used in the analysis of the process designs.

3. The facility design case study

Due to global competitive pressures many garment manufacturers have scaled down or closed their operations in the UK and moved overseas. Due to lower labour costs, in what is a labour intensive industry, production has increased in such areas as Asia. This study involves the design of a proposed overseas textile production facility which supplies garment manufacturers with rolls of material suitable for clothing manufacture. The case study organisation produces a range of cotton and lycra textile mixes which are used for garments such as t-shirts and women’s tights. In response to the relocation of garment manufacturers overseas and the need to reduce transportation costs of a bulky product the organisation has decided to supplement its UK operations and locate a textile production facility in Sri Lanka. The move will also lower costs due to lower labour rates and permit the design of a more efficient layout in a purpose built factory, as opposed to the current facilities which are placed across a number of locations and buildings within the UK. Previous work involving simulation in the context of textile manufacture includes [6,7,9]. Previous work involving the simulation of plant layouts includes [4,14,16,17]. The main stages in the production process are shown in Fig. 1. Each stage is staffed by a locally managed team and all material passes through the knit, preparation, dye, finish and despatch processes.

Each process is now described in more detail.

3.1. Knit

The knit process, also termed ring spinning [19], takes yarn from the warehouse and knits into 25 kg rolls of cloth. A product mix is created by allocating a number of knit machines to a product type in proportion to the mix percentage. Table 1 gives a product mix of seven main product types of different material and weight for the plant configuration to be modelled. After knitting, the 25 kg roll is placed in a doff box (rectangular container) and quality examined at one of three knit examination tables. After the quality examination the output from each knit machine is grouped separately to form a batch. This ensures that material within a batch is consistent as it is from the same knit machine and source yarn. With the current configuration this requires 48 batch areas (one for each knit machine). The batch quantity is determined by the dye machine type that this product type has been allocated.

3.2. Preparation

The yarn has now been knitted into sheets of material in 25 kg rolls. The preparation stage sews these individual rolls together into a batch termed a lane for dying. At this stage certain material types are set to shape using a heated conveyor termed a stenter. The process flow for the seven product types are shown in Fig. 2.

Product types 1 and 5 are processed through the prep (TF) flapper that sews the individual 25 kg rolls from the knit process together. Product 2 requires setting on the preset stenter after sewing. Product 3 is sewn on the prep (UF), preset on the

![Fig. 1. Main stages in textile plant production process.](image-url)
stenter and then its edges are sewn into a tube on the monti-tuber machine. Product types 4 and 6 are sewn on the prep (UF) and preset on the stenter. Product 7 is reversed on the sperotto before sewing on the prep (TF). Material awaiting the sperotto, prep (TF) and prep (UF) processes are stored in the preparation storage area. Material awaiting the preset stenter and monti-tuber processes is stored in the greige (i.e. undyed cloth) storage area. After completion of the preparation process batches are stored in the dry storage area awaiting the dye process.

3.3. Dye

The cloth is dyed in one of three shades (dark, medium, light) in a dye machine which resembles a large domestic washing machine. There are four types of dye machine (1 lane, 2 lane, 3 lane and TRD) which have different load capacities. A lane relates to the capacity of one drum within the dye machine. The batch size is derived by multiplying the lane capacity with the number of lanes for each machine. The batch and lane size for each dye machine is given in Table 2. For example, material allocated for a 3 lane dye machine will consist of 3 lengths (lanes) of 9 × 25 kg rolls stitched together to form a batch. The lanes are transported between production stages as a batch to ensure material from the same source is kept together.

The allocation of batches to a dye machine type is undertaken before the knit process and is determined by product type (see Table 3). For example, batches of product type 1 will only be allocated to the 1, 2 or 3 lane dye machine types. The specific mix of machine types allocated to each batch from this selection is determined by the production schedule to ensure that a balanced load is achieved through all dye machine types. The reason this allocation is determined by the schedule before the knit stage is that batches must contain material from the same knit machine and so cannot be split or combined and the batch size for each dye machine is different.

The batches arrive at the dry storage area ready for dying by one of the dye machine types. Each batch must now be allocated to particular dye machine of the correct type. For example, there may be five 2 lane dye machines available. Dye machines must undertake a lengthy setup process when changing from one dye shade to a different dye shade and so rules have been developed for allocating a batch to a particular dye machine which aims to minimise the number of setups undertaken.

### Table 1
Product mix

<table>
<thead>
<tr>
<th>Product type</th>
<th>Product mix (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>6</td>
<td>28</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

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### Table 2
Batch size by dye machine

<table>
<thead>
<tr>
<th>Dye machine type</th>
<th>Lane size</th>
<th>Batch size</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Lane</td>
<td>9</td>
<td>9</td>
<td>225</td>
</tr>
<tr>
<td>2 Lane</td>
<td>9</td>
<td>18</td>
<td>450</td>
</tr>
<tr>
<td>3 Lane</td>
<td>9</td>
<td>27</td>
<td>675</td>
</tr>
<tr>
<td>TRD (2 lane)</td>
<td>8</td>
<td>16</td>
<td>400</td>
</tr>
</tbody>
</table>

---

![Fig. 2. Preparation stage process flow.](image-url)
Thus each batch must be allocated to the correct machine type for that product type and if possible a machine which has previously been used for the same dye shade. The rule for allocating a batch in the dry storage area to a dye machine are as follows:

1. If a dye machine of the allocated dye machine type is available, process the batch on this machine (idle machine). 
   otherwise
2. If the shade of the last batch on any dye machine of the allocated dye machine type matches the shade of the batch, wait in dry storage until this machine is available and process the batch on this machine (match shade). 
   otherwise
3. Wait in dry storage for the dye machine of the allocated dye machine type with the smallest queue. (shortest queue).

The dye process time is dependent on the dye shade and is adjusted for batch weight. Note a 3-lane (675 kg) batch on a 3-lane dye machine has a process time equal to a 1-lane (225 kg) batch on a 1-lane dye machine. After the dye process the wet material is unloaded into wheeled tubs (1 lane to a tub) and stored in the ‘tubs and wet storage’ area awaiting the finishing process.

3.4. Finishing

The finishing process dries and if necessary sets the shape of the material. The process map for finishing for the seven product types is shown in Fig. 3.

Note that the material is now held in a tub and consists of a lane (eight or nine 25 kg rolls) stitched together in a tube. The slitters slit open the tube to form a material length that is flapped to aid drying. Products 1, 2, 3 are passed through a further drying process. All products pass through the stenter machine that sets the material in its final width and weight and provides any chemical finishes that are required. Products 1, 4, 6, 7 are shaped by the compactor. All products are visually inspected individually as lanes and then batched and moved to the finished goods warehouse.

3.5. Despatch

Batches of material are held in the finished goods warehouse ready for despatch. Material is held for local, air or sea despatch in the proportion of 50%, 25% and 25%, respectively. Local despatches are undertaken daily. Air despatches wait for 5 batches in storage, then send all in storage 24 h later. Sea despatches wait for 10 batches in storage, then send all in storage 7 days later. There may be more than 5 or 10 batches sent by air or sea at a time if further batches arrive in the warehouse after the trigger levels have been reached and before actual despatch.

4. The simulation study

The aim of the simulation study is to assist the layout planning activity by estimating the quantity of work-in-progress inventory within the proposed facility to be situated in Sri Lanka. The estimation of inventory levels is critical because the relative bulk of inventory means the amount of floor-space required could be considerable. The need to sink drainage channels from the knit and dye machines and the size and weight of the machinery means that it would be expensive and time-consuming to change the factory layout after construction.

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Table 3

<table>
<thead>
<tr>
<th>Product type</th>
<th>Dye machine type allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 2, 3 lane</td>
</tr>
<tr>
<td>2</td>
<td>1, 2, 3 lane</td>
</tr>
<tr>
<td>3</td>
<td>1, 2, 3 lane</td>
</tr>
<tr>
<td>4</td>
<td>1, 2, 3 lane</td>
</tr>
<tr>
<td>5</td>
<td>80% 1, 2, 3 lane/20% TRD</td>
</tr>
<tr>
<td>6</td>
<td>50% 1, 2, 3 lane/50% TRD</td>
</tr>
<tr>
<td>7</td>
<td>TRD</td>
</tr>
</tbody>
</table>

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Fig. 3. Process route for finishing process.
The study collected data on the main stages within the production process and modelled seven product types through the factory using data from current experience of operations in the UK and from machine vendor estimates. The plant runs on a continuous (7 days a week, 24 h a day) production cycle with an efficiency rating used to compensate for lost resource availability due to machine setup and other downtime factors.

The simulation model was built using the ARENA [12] visual interactive modelling (VIM) system. Fig. 4 is a view of the animated model showing the proposed textile production facility. Entities flow through the system as product batches, shown as coloured circles on the animation display, with a colour representing each of the seven product types. A letter L, M or D within the circles represents light, medium and dark dye shade, respectively. The animation display shows the batches waiting simulation resources such as in the preparation area, the dye area and examination areas.

The simulation coding is extensive with over 100 elements, but Fig. 5 shows the main logic within the ARENA model itself. Here the seven product types are generated and flow through the simulation and use resources within the textile plant. The routing and process duration of each product type on each resource is defined in an Excel spreadsheet to allow the client to easily change parameters without the need to make changes to the simulation model itself. The logic for the allocation of entities/product batches to dye machines is also shown in Fig. 5. Here the logic of matching the product batch to dye machine outlined in Section 3.3 is implemented.

Model validation was undertaken by comparing output levels and lead-time measurements with projected figures from the scenarios defined. Detailed walkthroughs of the model were then undertaken with production personnel to validate the behaviour of each production stage in the simulation.

The main objective of the simulation study was to predict the amount of work-in-progress (WIP) in the proposed layout under two scenarios of dye capacity which has been identified as the bottleneck constraining overall plant capacity. The experimentation assessed the performance of the production system for two scenarios of a 28 'lane' dye facility and a 39 'lane' dye facility, representing target output capacity levels of 60 tons per week and 100 tons per week, respectively. The dye capacity details for each scenario are given in Table 4.

The production system is operated using the technique of line balancing and must therefore be balanced before results can be collected from the model. A balanced system will match output level with input level and maintain a steady level of WIP. The dye machines are the production bottleneck or constraint on capacity and so it is necessary to balance the system through this production stage. Because each batch of material is allocated a dye machine type at the knit stage it is necessary to balance the workflow through each dye machine type (i.e. the 1 lane, 2 lane, 3 lane and TRD) separately rather than the dye process as a whole. Thus to balance the system two factors are adjusted, the rate of input into the system (i.e. the output from the knit machines) and the mix of dye machine type by product type.

The simulation results report on the WIP amount, derived from the resource queue lengths reported in the simulation results, and thus provides a measure of storage area required for all major WIP areas. The simulation was run 100 times over a 5-week run period. The 100 runs are necessary because the variability in the system (derived from process time variability...
and independence of product flows) means that the output measure of interest, the storage area requirement, is a random variable and must be adequately characterised in order to make statistically valid conclusions. A run duration of 5 weeks for each replication was chosen in order to achieve steady state operation of the model for data collection. To calculate the maximum floor-space required for each storage area the maximum WIP amount at that location for each simulation replication is recorded on a spreadsheet. The 95th percentile of the sample of 100 measurements taken from the simulation replications is derived by selecting the 95th value from the sorted list of 100. This measurement is used in conjunction with the floor-space area for the relevant storage type to derive a maximum floor-space area required for each storage location for each of the 28 lane and 39 lane scenarios (Tables 5 and 6). For more details on the use of percentiles when estimating performance measures consult Law and Kelton [13].

Table 4
Dye capacity for simulation scenarios

<table>
<thead>
<tr>
<th>Dye machine</th>
<th>28 Lane scenario</th>
<th>39 Lane scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Machines</td>
<td>Lanes</td>
</tr>
<tr>
<td>1 Lane dye</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2 Lane dye</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>3 Lane dye</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>TRD (2 lane)</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>28</td>
</tr>
</tbody>
</table>

![Conceptual Logic for Product Flow through Textile Plant](image)

![Conceptual Logic for allocating Product on dye machine](image)

Fig. 5. Conceptual logic for ARENA simulation model.

Table 5
Floor-space required by storage area (28 lane scenario)

<table>
<thead>
<tr>
<th>Storage area name</th>
<th>Maximum WIP (95th percentile)</th>
<th>Storage area type (dimension)</th>
<th>Maximum area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knit exam</td>
<td>21 Rolls</td>
<td>Doff box (1 m²)</td>
<td>21</td>
</tr>
<tr>
<td>Knit batchup</td>
<td>48 Batches</td>
<td>Pallet (2.5 m²)</td>
<td>120</td>
</tr>
<tr>
<td>Preparation</td>
<td>37 Lanes</td>
<td>Wheeler (2.5 m²)</td>
<td>92.5</td>
</tr>
<tr>
<td>Greige</td>
<td>34 Lanes</td>
<td>Wheeler/stillage (2.5 m²/2.5 m²)</td>
<td>85</td>
</tr>
<tr>
<td>Dry storage</td>
<td>153 Lanes</td>
<td>Stillage (2.5 m²)</td>
<td>382.5</td>
</tr>
<tr>
<td>Tubs and wet storage</td>
<td>13 Lanes</td>
<td>Tub (2 m²)</td>
<td>26</td>
</tr>
<tr>
<td>Stenter</td>
<td>25 Lanes</td>
<td>Wheeler (2.5 m²)</td>
<td>62.5</td>
</tr>
<tr>
<td>Compactor</td>
<td>11 Lanes</td>
<td>Wheeler (2.5 m²)</td>
<td>27.5</td>
</tr>
<tr>
<td>Final exam</td>
<td>20 Lanes</td>
<td>Wheeler/A-frame (2.5 m²/2.5 m²)</td>
<td>50</td>
</tr>
<tr>
<td>Finished goods</td>
<td>32 Batches</td>
<td>Pallet (2.5 m²)</td>
<td>80</td>
</tr>
</tbody>
</table>
In summary the simulation was able to estimate the amount of factory work-in-progress (WIP), and thus floor-space area required, under two scenarios of a '28 lane' and a '39 lane' dye configuration. These related to two investment proposals providing two capacity capabilities of 60 tons and 100 tons, respectively. The dye stage was identified as the system bottleneck and so in order to balance the system enough work must be provided to the dye facility to ensure the machines are fully utilised, but not too fast a rate that queue build-up occurs. In order to achieve a balanced system the overall rate of work entering the dye facility was controlled by adjusting the rate of output from the knit process. However each product type is pre-allocated a dye machine type at the knit stage which means that the volume through each dye machine type (i.e. 1 lane, 2 lane, 3 lane, TRD) must be balanced separately. This was achieved by adjusting the volume mix on the four dye machine types. Because of this relatively complex procedure a number of trial simulation runs were necessary to adjust both overall product volume and the mix of products allocated to each dye machine type in order to balance the system. This process is complex because of the variability of the time lag between the decision taken at the knot stage and the effect of that decision when the batch reaches the dye area. This variability is due to each product batch taking an independent route through the intermediate preparation process and the variability of queue lengths at these intermediate processes.

5. Discussion

In the case study described a simple spreadsheet model could have been used to calculate maximum loading and thus inventory levels in a standard line facility layout. A discrete event simulation has the ability to carry information about each entity (by setting an attribute of the entity to a value) which was needed in this instance because the allocation of a dye machine type for each batch of material is made before the knit stage of the process in order to ensure consistency of material. Thus when a batch arrives at the dye stage it is allocated a machine based on an attribute set at the beginning of the process. Also the ability of the simulation to show queuing behaviour was essential because the overall objective of the study is to show the maximum inventory level, and thus floor-space requirement, necessary for the proposed facility layout. Thus discrete event simulation was chosen because of its ability to both store attribute values and to show queuing levels at an individual product level.

It terms of assessing the outcomes of the simulation study what became clear from the case study analysis was that discrete event simulation provided more than a quantitative analysis of floorspace, but generated qualitative data for decision making. Firstly the simulation demonstrated the relationship between decisions made at the knit stage and the effect of these decisions on the downstream dye stage. This issue was important because each production stage (e.g. knit, preparation, dye) had a separate manager responsible for their area of operations. Thus the simulation study underlined the importance of communication and collaboration between these areas in establishing a balanced production cycle and it was proposed to use the visual representation provided by the model as a training tool for the production stage managers in understanding the dynamics and relationships between operations. Secondly at an operational level the need to codify decisions made by personnel in the production process caused their assumptions to be questioned. Specifically, as part of the model data collection process, the rules regarding allocation of work to dye machines was classified and formalised after discussion with personnel.

The case study also demonstrated that one of the important factors in achieving client confidence in the model was the intuitive way in which the discrete event method represents elements such as machines, people and products as recognisable objects. The ability to observe the animation display, which incorporated the CAD drawings of the proposed facility layout, was seen as an essential check of accuracy from the client’s perspective. In retrospect it was clear that the study was undertaken on the basis of assumptions about how the process worked that were incorrect. The consequence of this was that additional time was required to form an understanding of the process requiring the project completion date to be extended. These qualitative outcomes are generated because simulation modelling is not just about analysing results from a model, but is a process that takes place over time. What the process of designing and building a model did offer was a way of initiating discussion amongst decision makers about the system in question through such actions as data collection, process mapping and visual inspection of the simulation animation display. Indeed it is not a requirement of a simulation...
modelling exercise that a model is actually built, but qualitative outcomes from the process mapping stage, for example, could generate useful knowledge. This elicitation of knowledge through the process of conducting a simulation study rather than simply an observation of model results has been termed ‘simulation for facilitation’ [15].

In this case study a line balancing approach to production planning was preferred by the client and the main objective of the simulation study was to predict work-in-progress levels under steady state or balanced conditions. Line balancing [10] is a common method used to maximise output from a serial line layout were the output of the line is traditionally thought to be determined by the stage with the least capacity. It should be noted however that the efficiency of a balanced line has been questioned [1,8]. Chakravorty and Atwater[2] compared a line balancing approach with Just-In-Time and Theory of Constraints methods of operating production lines and found that the line balancing approach did not perform best under any of the conditions in the study. In an earlier paper [3] however, they did find that line balancing could outperform JIT under conditions of high system variability, especially at low levels of inventory. A further use of the simulation model would be for it to be developed so it could provide a comparison between these operating policies before implementation of the plant.

6. Conclusion

A discrete event simulation model was used to estimate the size of storage areas required for a proposed overseas textile manufacturing facility. It was found to be an appropriate tool for this task through the use of its ability to carry information using entity attributes and its ability to show queuing behaviour. Discrete event simulation was also found to have the ability to facilitate knowledge through the day-to-day process of undertaking the study and providing qualitative outcomes. In the case study described it was found that the process of undertaking the simulation project initiated useful discussions regarding the operation of the facility covering areas such as the management of the departments and their interrelationships, the accuracy of data held on machine capacity, working practices such as shift patterns and examination of production rules that had evolved over time without any formal assessment of their appropriateness. What the case study does show is that discrete event simulation in its ‘facilitation’ role can provide qualitative understanding of behaviour over and above the normal benefits associated with this technique.

References