Digital twins report: Findings

7.1 Generic Abattoir Simulation Model

7.1.1 Discrete Event Simulation as a Methodology

Discrete Event Simulation (DES) (footnote 1) is a modelling technique whereby the simulation clock progresses from one event to the next. This non-uniform time step makes the simulation computationally efficient and means that this technique is perfectly suited for modelling flows through a system. One particular area where DES is employed to great effect is within the manufacturing sector, where simulation and evaluation of factory flows, and production processes is common practice (footnote 2) (footnote 3) (footnote 4).
DES provides a risk-free environment to gain deeper insights and test decisions prior to making changes in the real-life manufacturing operations. It can capture uncertainty in the operations and more detailed information than an analytical model or spreadsheet analysis hence providing accuracy and a precise forecast.
Certain data requirements must be met in order to construct a DES model. An example of the information needed for the generic abattoir simulation is presented in Table 1. In DES models, input variables can be stochastic (or random variables). As an example, process timings may not be exact and therefore difficult to capture, especially for manual processes, which are likely to vary depending on operator skill. The effect of this uncertainty can be incorporated into the model through the use of statistical distributions.

Table 1. Lairage and Slaughter Processes and Resources.

Process number	Process name	Process time	Resources	Resource capacity (footnote 5)
1	Livestock Unloading (Temperature Ambient)	10 minutes per batch	-	-
2	Ante – Mortem Inspection	5 second per pig	Driver/Inspector	1
3	Pigs Rested in Lairage	1 hour per batch	-	-
4	Gas Stun Minimum 85% CO2	30 second per pig	Gas Room	6
5	Shackle Carcass	5 second per pig	Worker	1
6	Bleed Out	30 second per pig	Worker and Conveyor	30
7	Scald (61-62? scalding tank temperature	5 minute per pig	Machine and Conveyor	50
8	De-shackle	10 second per pig	Worker	1
9	De-hair	10 second per pig	Machine and Conveyor	10
10	Remove Toenail, Tendon Cut and Insert Hooks	30 second per pig	Worker	2
11	Manual Singe	30 second per pig	Worker	2
12	Carcass Stamping	20 second per pig	Worker	1
13	Trim Sticking Wound	30 second per pig	Worker	2
14	Pizzle Removal / Initial Opening	30 second per pig	Machine worker	2
15	Automatic Opening	30 second per pig	Machine	2
16	Manual Rectum Separation	10 second per pig	Worker	1
17	Evisceration	30 second per pig	Worker	2
18	Carcass Trim Inspection and Removal (Check Point 1)	30 second per pig	OV	2
19	Pluck Drop	30 second per pig	Worker	2

Process number	Process name	Process time	Resources	Resource capacity (footnote 5)
20	Automatic Carcass Split	5 second per pig	Machine and Conveyor	10
21	FSA Inspection 1	15 second per pig	OV	2
22	Pizzle-Root Removal (Check Point 2)	10 second per pig	OV	1
23	Flare Fat and Kidney Release	10 second per pig	Worker	1
24	QA Carcass Inspection	35 second per pig	OV	2
25	FSA Inspection 2	35 second per pig	OV	2
26	MLC Grading	30 second per pig	Worker	2
27	Excess Blood Meat Removal	60 second per pig	Machine and Conveyor	30
28	Tonsil Removal	30 second per pig	Worker	2
29	Carcass Health Mark Stamp and Kill Number	10 second per pig	OV	2
30	Spinal Cord Removal	10 second per pig	Machine	1
31	Carcass Trim Inspection and Removal	30 second per pig	OV	2
32	Carcass Inspection and Trim (free from visible physical contamination)	30 second per pig	OV	2
33	MLC Weigh and Grade	5 seconds	Machine	1
34	Bulk Weigh / Label	5 seconds	Machine	1
35	Flare Fat Gland Removal	10 seconds	Machine	1
36	Fillet Drop and Trim	5 seconds	Machine	1
37	Carcass Rapid Chill -18 °C to –30 °C (footnote 6)	1 hour	-	-
38	Carcass Chiller: Carcass temperature <7 7°C in 24 hours, target <5 5°C Polish / Automatic Singe	1 day	-	-

The process flow model provides insights into numerous KPIs such as: resource utilisation of both staff and equipment, bottleneck location, throughput, buffer capacity, and work in progress (WIP). After areas for improvement have been identified, any proposed changes to the running of the baseline factory or any of its processes can be simulated in the model reducing the risk of implementation. These experiments are commonly known as 'what-if' scenarios' and can be used to assess a wide range of changes on the KPIs.

The steps taken in developing a discrete event simulation model are presented in Figure 1. First, the data mentioned in Table 1 needs to be collected. This data is used to build the baseline ('as-is') model. In order to make sure this model represents the real system, it needs to be verified and validated by comparing model outputs to real-life system performance indicators. Once validated, the model can then be utilised to run various experiments/scenarios.

Figure 1: Steps of a DES study

7.1.2 'What-If' Scenarios of a DES

The 'what-if' scenarios that could be carried out using DES are as follows:

- **Validation of New Technology Introductions:** DES can be used as a validation tool to evaluate the effects of technological improvements such as automation and new tooling to provide more accurate or valid estimates of the incremental costs and benefits of alternatives on KPIs such as throughput, resource utilization, WIP etc.
- **Layout Optimisation:** Factory layout reconfigurations are usually time consuming and expensive. DES is one of the most commonly used methods for visualising factory layouts to assess various scenarios to assist production managers with layout planning. These scenarios include but are not limited to setting the positions of different machinery, testing cellular production line vs. standard assembly line, positioning material handling equipment effectively. Significant benefits such as efficient material flow, decreased lead times, reduced manufacturing costs, and increased profit can be achieved (footnote 7).
- **Inventory Level Decisions:** Holding inventory is necessary for a firm and determining the appropriate replenishment policy that will minimize inventory holding and order costs under probabilistic demand is usually challenging (footnote 8) (footnote 9). A discrete event simulation methodology is suitable to capture the dynamics of this problem. Without interfering with the real system, different replenishment strategies can be evaluated to find the most suitable one that makes sure no disruptions to the production schedule are made.
- **Resource Allocation/Optimisation:** Labour related scenarios can be used to analyse the impact of the number of workers, their skill sets and shift patterns. Such analysis would help increase the utilisation of labour while meeting production deadlines. Moreover, machine capacity and maintenance related scenarios can be tested. Most suitable number and capacity of material handling equipment can be defined.

7.2 Generic Abattoir Model Process Flow

The process flow was mapped based on the three main stages involved in livestock processing; namely, lairage, stunning, and slaughtering. Prior to slaughter, animals are held in lairage pens, which should display stock density notices and the date and time of arrival and contain adequate facilities for feed and water. The lairage requirements are checked by the Official Veterinarian (OV) who also carries out AM inspections of the animals to identify any conditions, either physiological or disease-related, that would cause adverse effects to animal welfare or human health. Animals are then led to the stunning pen through narrow walkways in a single file. Stunning is carried out to render the animal insensible to pain prior to being slaughtered. There are different methods of stunning employed in UK abattoirs. Manual stunners are commonly used in small slaughterhouses and the three-point automatic stunning conveyor is the more advanced electric stunning approach used. The generic process flow used in this study assumes that a gas stunning process is in use. Both captive bolt and electrical stunning induce instantaneous unconsciousness while CO2 or other controlled atmosphere methods require a time lag of 20 or more seconds before the animals exhibit loss of posture (LOP). Once the animals have been stunned, a door on the side of the stunning pen is opened and the stunned animals are conveyed down to the bleeding area. After bleeding, carcasses are sent via a conveyor to the evisceration point where the viscera is removed. The carcasses then progress through splitting, labelling and chilling processes. Inspections are carried at various critical control points in the process flow and it is a highly stochastic process (footnote 10) implying that considerable aspects of the inspection processes are carried out manually (through visual checks and palpations where required) and the quality and level of scrutiny of livestock differs from batch to batch and across abattoirs (footnote 11).

Table 1 shows the processes of the generic processing scenario at a pig abattoir in sequence. The original process flow chart can be found in Annex 1. For each process, the time, resources and capacities are needed. If the carcass are carried by an overhead conveyor, process time can be estimated from the conveyor length and speed. Alternatively, conveyor length and speed can be directly used in the model.

To give an example, Table 1 is populated by gathering information on average duration estimates for each process from subject matter experts. For each process the assigned resources (machine, worker, inspector, OV, etc.) are identified with their capacity. Each worker can only work on their designated process. The same rule applies for the OVs. Sharing workers and OVs between processes is not permitted by the FSA.

Throughout the process flow (after stunning), the carcasses are carried on overhead conveyors. Where the process duration is assumed to be determined by the conveyor speed, the resources required on Table 1 are stated as ‘conveyor’. The generic facility used for the modelling in this study is assumed to work five days a week for 10 hours per day, processing livestock supplied from various farms. It is also assumed that livestock are brought into the lairage in batches, which are not combined.

7.3 The Generic Simulation Model Specifications

The generic abattoir simulation model used in this project consists of 5 areas. The first one is the user interface where an analyst/user can alter the selected variables to run scenarios. Second is the logic where the process flow and modelling related rules are defined. The third and fourth areas are the 2D and 3D animation, respectively, where the process flow is visualised. The last area is the KPI dashboard where the selected model output statistics are shown.

7.3.1 User Interface

User interface consists of selected variables related to the process flow in order to run ‘what-if’ analysis (Figure 2). These variables are:

- livestock batch size and interarrival time to define when and how many livestock arrive at a time to the facility

- AM inspection duration to define the time spend for the OV to check the newly arrived livestock
- gas stunning duration and capacity in order to define how many livestock can fit into the gas stun machine and how long they should stay there
- duration of singe operation, which may change depending on whether it is a manual or an automated process
- duration of carcass stamping operation, which may change depending on whether it is a manual or an automated process
- check point inspections and FSA inspections can be achieved by the FSA OV or by using the AI technology to detect anomalies. If it is achieved by an OV it would take longer. AI technology would shorten the duration of this inspection considerably. In theory using AI image detection technology the error rate would also decrease during the inspection stages
- MLC weight and grade operation duration. The duration of this operation may change whether it is a manual or an automated process. If it is an automated process the duration would decrease considerably and the errors on grading would lessen through the use of AI image detection.

Figure 2: Simulation Model User Interface

7.3.2 Logic

Process flow from the point of receiving the livestock to chilling the fillets is defined in the logic section (Figure 3). Operations are divided as AM and PM. All the resources including workers, OVs and machineries are defined here. Process Flow Logic is enhanced with the new Material Handling Library of Anylogic Software. PM operations are placed on a conveyor system which provides more reliable representation of the processes. It allows defining length, speed, and capacity of the conveyors which makes the model more flexible to be applied to any specific abattoir layout.

Figure 3: Simulation Model Logic representing Key ante and post-mortem inspection processes

7.3.3 2D and 3D Animation

The use of 2D and 3D visual displays has many benefits. It has been proved that animation results in more effective communication, verification and validation, and experimentation. This can lead to an improved understanding of the real system and a better solution for the decision maker. As a result, both 2D and 3D animation was developed for this generic model.

Figure 4: 2D animation of abattoir layout and processes

In Figure 4, the whole process flow can be seen. It starts with receiving livestock and continues with the lairage. The first process at the facility is gas stunning followed by shackling carcass. A closer look to these operations in 2D can be seen in Figure 5.

Figure 5 – Closer Look at 2D Animation of Abattoir Process (Lairage).

Inspection points are shown in red. These are the points where OVs are inspecting the carcass for various diseases. One possible improvement is to use AI technology in order to detect anomalies in the carcass. As a result, to run the related scenarios this option is given in the user interface.

From the point that the carcass is shackled the process continues on an overhead conveyor until the last operation which is fillet drop and trim. After this operation the fillets are sent to rapid chill and chiller. After staying in the chiller for about a day, the fillets are sent out.

Figure 6 – Ante-Mortem Inspection and Lairage in 3D.

Screenshots from the 3D animation can be seen in Figure 6, Figure 7 and Figure 8.

Figure 7 – Gas Stunning and Shackling Carcass Operations in 3D.

Figure 8 – Bleed-out, Scalding and De-hairing Operations in 3D.

7.3.4 Dashboard

At last, a dashboard is introduced in order to capture the effect of input variables or interventions on the KPIs. Currently, the dashboard consists of the indicators of total throughput, utilisation of the OVs and utilisation of the abattoir workers. A screenshot taken of the dashboard during the simulation run can be seen in Figure 9.

Figure 9 – Dashboard Showing Throughput, Utilisation of OVs, and Utilisation of workers.

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5. Resource capacity in DES context refers to number of entities that could be processed in parallel. In this model it is the number of livestock that could go through a particular process at the same time. If the resource is a worker, it refers to the maximum number of available workers for that particular process. If the resource is a machine, it refers to the maximum capacity of this machine.

6. The pig carcass after trimming and washing (at ambient temperature) enter the chilling room. To shorten the chilling time of carcass, some abattoirs use fast cooling technology (-20? for 90 minutes) prior to entering the chilling room. The chilling room temperature ranges from 0-4?, and chilling time is about 10-15 hours. The carcass is transported on a rail by an unloading machine, segmented and transported via automatic transfer conveyors to personnel cutting stations.

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