Simulating value creation opportunities for FSA inspection processes using digital twins

Area of research interest: Meat Hygiene Research Programme
Planned completion: 15 September 2022
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Conducted by: University of York, Manchester, Sheffield and LeanSig Limited, Food Standards Agency, Science and Technology Facilities Council
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Digital twins report: Executive Summary

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Executive summary

This project was developed following a 21st century abattoir review commissioned by the Food Standards Agency (FSA) and the Science and Technology Facilities Council (STFC) to explore areas where advanced technologies could augment or enhance the delivery of FSA’s official controls for meat safety, traceability and authenticity in line with the FSA’s operational transformation agenda. The review captured the current state of processes, practices and technologies used in UK abattoirs, and provided independent recommendations on the most appropriate data and technology capabilities of the STFC, as well as other technologies available on the market to support the delivery of official controls (Ante- and Post-Mortem inspections) and improve Food Business Operators (FBOs) operational efficiencies. The preliminary findings of the 21st century abattoir review were used to propose feasible and scalable development areas during a joint FSA-STFC Sandpit event held in October 2019.

Following the sandpit, a consortium led by the University of Sheffield AMRC received joint funding from the STFC and the FSA to explore advanced technology interventions that could upgrade certain key meat processing and inspection operations from the 18th to the 21st century. The project aimed to simulate a specific PM inspection critical control point (visual contamination checks and offal inspection) using digital twins to identify opportunities for enhancing inspection quality and failure prevention through scalable people-technology-machine interfaces. The objective was to build a simulation model of offal inspection processes to capture the value streams of people, processes and technology, and identify potential opportunities for improving the current inspection process in UK abattoirs.

This study uses discrete-event simulation (DES) modelling with virtual testing of technology, people, and process configurations to allow the exploration of ‘what-if’ scenarios to predict and optimise the system behaviour. A generic simulation model of a pig abattoir process flow was developed to provide the FSA with a methodology for visualising how equipping inspectors with technologies could support efficient and accurate operations. In addition, this proof of concept would also contribute to the FSA strategy to deploy the right balance of technology and labour via the new operational transformation agenda.

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Digital twins report: Introduction

2.1. One of the key objectives of this project was to identify current and future opportunities for deploying advanced technologies in the offal inspection process, and identify the Key Performance Indicators (KPIs), causes of delays, inefficiencies, and opportunities.

2.2. The second objective was to develop a model to facilitate virtual testing of technology, people, and process configurations and to explore 'what-if' scenarios for predicting and optimising the impact of interventions on offal inspections.

2.3. The third objective was to simulate a live connected abattoir to understand the effectiveness and appropriateness of digital twin applications for virtual testing of potential interventions and investment opportunities to improve offal inspections.

2.4. This report explains the discrete event simulation model, which has been developed for a generic pig abattoir process flow to provide policy makers with a flexible test bed for visualising how an inspection process can be transformed and optimised using technologies. In addition, this proof of concept aims to help the FSA understand the impact of technology intervention at different critical control points to inform the development of future inspection strategies that consider the right balance of technology and workforce deployment.

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Digital twins report: Background

3.1. The Ante-Mortem (AM) and Post-Mortem (PM) inspection protocols for meat quality and safety assurance in UK abattoirs are set out in the operational guidelines of the Food Standards Agency's (FSA) manual for official controls. These official guidelines outline the processes, resources, and reporting protocols used by Official Veterinarians (OVs) and Meat Health Inspectors (MHI) to carry out and file both AM and PM inspection reports.

3.2. However, findings from the "Review of 21st Century Abattoirs" showed that it is currently very challenging for the FSA and FBOs to empirically monitor the resource constraints KPIs of AM and PM inspections due to the variations in production throughputs, species processed, and kill-speeds in abattoirs across the UK.

3.3. To enable FSA inspectors and FBOs to discharge their duties efficiently and accurately, it is imperative to develop deeper insight into the process functionalities and relevant metrics that directly impact inspection efficiency, quality and safety scrutiny within abattoirs.

3.4. With the prevalence of manual inspection processes and the complexity of the inter-agency landscape involved in the delivery of official controls, there is an imminent need to improve the current human–machine or socio-technical systems that underpin AM and PM inspections.

3.5. There is scope to augment existing inspections with imaging technologies, line-mounted and hand-held sensor technologies, Artificial Intelligence (AI)-based fault detection and diagnostic technologies and track-and-trace applications. However, a crucial first step is to carry out a detailed mapping of the current or ‘as-is’ inspection operating model to identify areas where technology interventions would have the most valuable impact in enabling a balanced and effective socio-technical inspection system.

Digital twins report: Aims and objectives

The study set out to address the following questions:

4.1. What are the process functionalities and relevant metrics that have direct implications for inspection efficiency, quality and safety assurance in abattoirs?

4.2. How can existing inspection processes, routines and data streams be augmented with available advanced technologies?

4.3. Can the benefits of technology or process interventions on existing operations be demonstrated using digital twins or a simulation model?

Digital twins report: scope of the review

5.1. The insight into the process functionalities and relevant metrics for meat inspections presented in this review were developed through;

5.1.1. A detailed mapping of the process layout/configuration requirements of AM/PM critical control points.

5.1.2. A detailed mapping of the manpower requirements and standardized operating protocols for AM/PM inspections and reporting by OVs.

5.1.3. A detailed outline of in-process KPIs and constraints of AM/PM inspection processes and reporting.

5.1.4. A relative and absolute benchmarking of available technology interventions that can be incorporated to improve the accuracy and efficiency of specific AM/PM inspections beyond what is obtainable from visual checks, palpations and offal incisions.

5.1.5. An evaluation of the existing capabilities to incorporate recommended technology interventions within a specific inspection process (offal inspections).

5.2. By reviewing current inspection processes and conducting a technological assessment to explore available/scalable technological interventions, the scope also entailed;

5.2.1. Matching inspection process, resource and technology requirements to abattoirs by throughput, species and kill speed.

5.2.2. Informing investment in the right layout, process and technology interventions with an appropriate balance of human and technology interphases to facilitate 21st century abattoir inspections by the FSA and FBOs.

5.3. To operationalise the scope highlighted in 4.1 and 4.2, a DES model was developed for a generic pig abattoir process flow to visualise how an inspection process can be transformed using technologies.

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Digital twins report: Methodology

6.1. The research team carried out a Gemba walk (footnote 1) to observe offal inspection processes at case abattoirs and spent a day in each slaughterhouse, interviewing various respondents with oversight and inspection duties to understand the current system of AM and PM meat hygiene inspections vis-à-vis the FSA Manual for Official Controls (MOC).

6.2. The respondents included FBO management and staff, plant inspection assistants (PIA), Official Veterinarians (OVs), Senior Meat Hygiene Inspectors and Official Auxiliaries (OAs).

6.3. In addition to observing critical controls points, the team also conducted a benchmarking review of available, applied and scalable technologies for optimising existing inspection process.

6.4. Using the detailed process map developed from observing live inspections, a DES (footnote 2)/digital twin was used as a supporting digital technology to trial possible innovations in a risk-free virtual environment prior to introducing new technology or making changes to existing inspection processes.

6.5. Determination of the future-state of inspection process by modelling a series of use cases of current state operations and simulating future states (post intervention), thereby providing an excellent starting point for the development of a digital twin.

1. A Gemba Walk is a technique used to observe and understand how work is being performed. Gemba is taken from the Japanese word gembutsu, meaning “real thing” or “real place,” and a Gemba Walk has the following elements: observation - watching people perform work in-person; location - observing people at the actual location where work is performed; teaming - interacting with people performing the work. (Dalton, 2019).

2. Schriber, T.J. & Brunner, D.T. (1997) Inside Discrete-Event Simulation software: How it works and why it matters. Paper presented at the Proceedings of the 1997 Winter Simulation Conference. https://doi.org/10.1145/268437.268441.

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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
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

Process number	Process name	Process time	Resources	Resource capacity (footnote 5)
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.

1. Schriber, T.J. & Brunner, D.T. (1997) Inside Discrete-Event Simulation software: How it works and why it matters. Paper presented at the Proceedings of the 1997 Winter Simulation Conference. https://doi.org/10.1145/268437.268441

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4. Huynh, B. H., Akhtar, H., & Li, W. (2020). Discrete Event Simulation for Manufacturing Performance Management and Optimization: A Case Study for Model Factory. Paper presented at the 2020 9th International Conference on Industrial Technology and Management (ICITM). https://doi.org/10.1109/ICITM48982.2020.9080394

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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Digital twins report: Limitations

This study proved that a simulation model or a digital twin could be used to demonstrate the benefits of suggested technology or process interventions on existing operations. However, due to covid restrictions the planned visits to any particular abattoir were not possible. Hence, the necessary data to tune the model could not be collected. This prevented us from providing case specific 'what-if' analysis and results.

A user interface is provided for the model to quickly run several scenarios on the technology and interventions. However, layout related interventions would require changes in the model structure itself such as defining the lengths and speed of the conveyors.

While this model provides an excellent starting point for the development of a digital twin, the right sensors and Internet of Things (IoT) technology for live data collection points may change from one abattoir to another based on the machine/technology used. While the model can be connected to a database, interoperability issues between the live data connection technology (sensors, IoTs, cameras) and the databases need to be considered.

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Digital twins report: Future recommendations

9.1 Technical recommendations

9.1.1 Optimisation with DES

AI integration to DES is an ongoing area of research. A number of AI software add-ins have become available, which makes the inclusion of certain AI methodologies easier to implement to facilitate the real-time evaluations of various 'what-if' scenarios in abattoir inspection processes. Such AI methodologies could allow simulation of potential cost-benefit analysis of proposed interventions to abattoir inspection processes prior to investing in actual infrastructure or technology. This can be achieved by rapidly evaluating the input parameters to find the best layout, configuration of machines for production scheduling, utilisation of employees for workforce planning etc. while considering specific abattoir settings. As a next step, an optimisation algorithm could be integrated to this generic abattoir simulation model to optimise resource allocation in specific abattoirs.

9.1.2 DES Digital Twin

Digital Twin is most commonly defined as a virtual representation of a physical asset, system or process used to detect, prevent, predict, optimize and deliver business value through real time analytics. A further study is thus required to develop the proposed DES digital twin with better data inputs for understanding both what is currently happening and what may happen in future technology-augmented inspection processes. Advancing the current model will provide the FSA with a tool for running risk-free simulation before introducing any actual changes to the inspection processes. To this end, the FSA and abattoir management can ensure consistent delivery against safety, quality, cost and other productivity objectives (footnote 1). This would require further validation of the proposed model to determine its viability through a series of use cases where the current state will be modelled and the future case be simulated, thereby providing an excellent starting point for the development of a comprehensive DES digital twin of abattoir inspections.

9.1.3 Hybrid Model (PhysiNet) Digital Twin

Discrete event simulation models require expert knowledge and advanced modelling techniques but can be used almost immediately after being developed. However, compared to AI-based models, DES models may be less accurate because they tend to be over-simplified as key system non-linearities may be ignored to reduce modelling complexity. Moreover, parameters in DES models may sometimes be estimated or inaccurately determined. These factors decrease the fidelity of DES-based digital twins and to improve the accuracy of such model predictions, engineers often have to redevelop the model by comparing the prediction and measurement to other modelling approaches such as AI-based models (Figure 10).

Figure 10: PhysiNet model

Another approach to building relevant digital twins for the FSA is using AI-based methods (footnote 2). However, such models require a reasonable amount of data, which is challenging to obtain for new systems or processes such as the proposed model that has been developed with limited data. Nonetheless, there are future opportunities to further investigate the established theoretical hybrid model (PhysiNet) (footnote 3)] (Figure 10) by combining discrete event simulation and the AI-based models to capture the whole life cycle of abattoir inspection systems (i.e. from the beginning with insufficient data to the point where sufficient data is generated from connected devices). As more data is generated from the actual deployment of connected digital devices, such hybrid models could significantly improve inspection processes by providing near accurate simulations and predictions of inspection process requirements and performance parameters.

9.2 Managerial Recommendations

9.2.1 Socio-technical balance

- the nature of meat inspections implies that any viable change initiative such as the newly proposed operational transformation framework must be based on a well-defined “socio-technical proposition”.

- the central idea here is that the work systems of MHIs, OVs and field operators comprises both a social system (including the staff, working practices, job roles, culture and goals) and a technical system (the tools and technologies that support and enable work processes).
- these elements together establish a single system of operating protocols and the technical and social elements have to be jointly designed (or redesigned) and congruent for the efficient delivery of inspection operations.
- to meet the FSA transformational goals, a crucial extension of this work is to understand and simulate how people (MHI, OVs and other field and back-office operators) and systems can be modelled to work together under both nominal and uncertain conditions, building on digital twin constructs.
- a logical next step in advancing this project is to engage with operators in the field through focus groups, Gemba walks and other ethnographic research methods to understand granular details of day-to-day inspection operations such as the key human-technology interphases (e.g., tasks description, timing, reporting and data requirements) that underpin the delivery of inspection protocols at each critical control point, the task bottlenecks, failure modes and recovery strategies.
- this will facilitate the development and training of simulations of optimal human-technology augmented operations as well as models for detecting and countering the adverse effects of communications bottlenecks and disruptions.
- another focus of this proposed activity would be to identify the requisite training, upskilling and capacity development needs along with cost-benefit assessment that the FSA could use to prioritise the various socio-technical transitions required to prepare different categories of staff for transitions in alignment with the operational transformation strategy.
- such simulations could also be expanded using primary data to model not only individual behaviours but also the processes and data that capture the interactions and interdependencies of different FSA staff (field, front-office and back-office) that support inspections.

9.2.2 Capacity Planning

- the recent pandemic and resulting staff shortages led to major capacity planning challenges for both the FSA and the industry, which had to be developed and executed in real time as the events unfolded. With sudden staffing issues arising in pig processing plants, coupled with related export delays and a surge in demand ahead of Christmas, the agency had to deal with a weekly backlog of at least 40,000 pigs on farms across the UK.
- scenario planning around capacity issues is therefore crucial, but requires a detailed understanding of the capacity constraints, bottlenecks and opportunities across the various field operations run by the FSA in order to inform future capacity planning for service resilience to sudden disruptions.
- this would require detailed mapping of the communications protocols among FSA teams and the development of a detailed capacity requirement blueprint for different inspection tasks (for example, abattoirs, export certification etc.) to feed into a digital twin model for capacity planning that is as agile as it is reliable, to inform evidence based decision making.
- this would facilitate the running of strategic and operational scenarios based on real-life capacity parameters within a configurable virtual environment where problems and effective response can be simulated, and response strategies developed prior to facing real challenges.

9.2.3 Transformational change feasibility and viability assessments

- the nature of meat inspections is rapidly changing, with several new propositions currently undergoing feasibility and viability assessments.
- one such feasibility initiative which could potentially change the way meat inspections are conducted is the idea of mobile slaughter units (MSUs) and the assessment of their fitness

for purpose, including how they should be financed, the viability of docking stations at retail outlets, the potential value streams to stakeholders, and the implications for FSA MHI and OVs evolving role within such scenarios.

- another of such feasibility assessments includes developing bespoke regulatory frameworks under the new operational transformation strategy for different animal stunning protocols (for example, Shechita and halal) as well as modelling the outcomes of technology enabled regulation of different stunning approaches to demonstrate/validate welfare monitoring to customers (for gas and electric stunning approaches) and transform welfare reporting measures using technologies.
- these and other transformational initiatives can be modelled using digital twins to develop sufficient evidence base in a virtual environment that is fine-tuned with real-world parameters prior to developing regulatory or operational frameworks for the FSA and FBOs .

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Digital twins report: Conclusion

A proof-of-concept simulation model is being provided to assess impact of the improvement opportunities. The developed generic simulation model on the abattoir process flow provides insights into how an inspection process can be optimised and then transformed using technologies. It offers an opportunity analysis for the FSA to equip its inspectors with latest technologies to increase efficiency and reduce inspection inaccuracies. In addition, this proof-of-concept has the potential to help the FSA understand the impact of technology intervention at different critical control points to support a strategy for deploying the right balance of technology and workforce for inspections. This study showed the capabilities of DES modelling to simulate where and how interventions can be made to increase the inspection process efficiencies, while optimising the use of resources.

This study is a starting point for the development of digital representations of abattoir flows. To adapt the generic simulation for a particular abattoir, the data points that are shown in Table 1 need to be collected and validated with stakeholders. In addition, to update the layout, a CAD drawing of the abattoir layout plan should be imported to the model to set the machineries and conveyors to the right scale and orientation. All the data points in the model can be connected to a database for automatic update on the current state of the system.

To develop a digital twin of the system using the current model, live databases that are connected to the sensors at the data points are required. The right sensor systems may be different for different abattoirs. A generalised sensor (such as RFID, tags, cameras) /IoT technology systems have to be investigated to be able to spread the usage of this technology. Digital connectivity through sensors, IoT devices and innovation in data governance can complement the development of a more robust predictive digital twin model. This study also contributed theoretically to solving regression problems in developing a digital twin by combining both the discrete event simulation model and neural network model by automatically assigning different weights to each of the models.

The advantage of developing a hybrid model solves the problem from the beginning of the digital twin development when there is not enough data and facilitates the incorporation of neural network solutions at later stages with higher prediction accuracy. It is observed that the simulation result of this novel approach leads to lower mean squared errors (MSE) or differences between model estimates and actual values, compared to neural network and discrete event simulation models. We found that adding a discrete event simulation model helped PhysiNet find better local minima.

To summarise, this project provides an enhanced version of a generic abattoir process flow simulation model in which selected process variables could be updated through a user interface. The model is improved with 2D and 3D animation and this proof-of-concept study set the stage for further work that needs to be done to validate and amplify this model. Furthermore, a detailed list of technical and managerial recommendations has been produced for future studies, suggesting investment in these areas could enhance the ability of FSA to deliver its protocol more efficiently with better accuracy while overcoming its resource constraints.

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Digital twins report: Annex 1: Original generic Abattoir process flow chart

The following table lists all Inputs, Primary processes, Secondary processes and Waste streams in the generic abattoir process flow chart. The individual items are presented in approximately the same relative positions as on the flow chart. However, close proximity of items does not necessarily indicate a direct link with other entries.

The flow chart itself does illustrate linkages. Examples include links between: slapmark ink and sticking of casualty; bleed out and category 3 waste; anti-foam and water and de-hair; and carcass tags/flags and pluck drop.

Inputs	Primary process	Secondary process	Waste streams
Pigs arrive from farms	1.1 Livestock unloading (temperature ambient)	1.1.1 Holding in Casualty/isolation pen	Category 2 waste
Animals dead on arrival (DOA)	1.2 Ante-Mortem inspection	1.1.2 Casualty Slaughter	-
Slapmark ink	1.3 Pigs rested in Lairage	-	Water, feed and bedding waste

Inputs	Primary process	Secondary process	Waste streams
Captive bolt gun (optional)	1.4 Pigs provided water/feed (optional)	1.1.3 Sticking of casualty	-
Water, feed, bedding	1.5 Transfer to Gas stunner/electrical stunning pen (optional)	-	-
Delivery of CO2	1.6 Gas Stun minimum 85% CO2	-	-
-	1.7 Electric Stun 1.3 amps over 3 seconds/captive bolt (optional)	-	-
Shackle	1.8 Shackle Carcass	-	-
-	1.9 Sticking (Gas-stun to stick 75 seconds, electrical stun-stun to stick 15 seconds)	-	-
-	1.10 Bleed out (minimum 3 minutes)	-	Category 3 waste
-	1.11 Scald (approximately 7 minutes at 57 to 63 degrees)	-	Water
-	1.12 De-shackle	-	-
Anti-foam and water	1.13 De-hair	1.14.1 Buffering Rail (optional)	-
Hook Gambles	1.14 Remove toenail, hair (optional), tendon cut and insert hooks	1.14.2 Toenail removed (optional)	Category 2 Waste
Bungs, water	1.15 Manual singe/dry polish/automatic singe 1/head and foot brush/wet polish/Automatic Singe 2	1.14.3 Bung wash (optional)	-
-	-	1.14.4 Bung insertion (optional)	-
-	1.16 Fore Trotter Hair removal and pruning (optional)	-	-
-	1.17 Hind Trotter hair removal and pruning (optional)	1.16.1 Manual head brush or shave (optional)	-
Carcass ink	1.18 Carcass stamping (optional)	-	-
-	1.19 Trim sticking wound	-	-
-	1.20 Pizzle removal/initial opening	-	-
-	1.22 Manual rectum separation/emergency bunging (optional)/testicle release	1.22.1 Breast bone saw (optional)	-
-	1.23 Evisceration	-	-
Carcas tags/flags	1.24 Carcass Trim inspection and removal (check point 1 and 2)	1.24.1 Offal FSA inspection	Category 2 Waste
-	1.25 Pluck drop	1.24.2 Transfer to Offal Breaking area	-
Water	1.26 Pluck removal (hanging)	1.24.3 Transfer to Green Offal Room	Water
-	1.27 Automatic Carcase split	-	-
-	1.28 Manual split (optional)	1.26.1 Tongue wash (water)	-
-	1.29 FSA inspection	1.29 FSA inspection	-
-	-	1.26.2 Liver wash (optional)	-
-	1.30 Check point 2 and pizzle-root removal	-	-
-	1.31 Flare fat and kidney release	-	-
-	1.32 QA carcase inspection 1	1.31.1 Pleurisy removal (optional)	-
-	1.29 FSA inspection	-	-
-	1.33 MLC Grading	1.32.1 Transfer of Carcass to detained room	-
-	1.34 Loosen Jowls 1 and 2	-	-
-	1.35 Rectification (optional)	1.32.2 Carcase trim (optional)	-
Dolavs and Tote Bins	1.36 Excess blood meat removal	-	-
-	1.37 Tonsil removal	-	Category 3 Waste
-	1.38 Carcase Health mark stamp and kill number	-	-
-	1.39 Spinal cord removal	-	-
Carcass ink	1.40 Carcase trip inspection and removal	-	-
-	1.41 (CCP01) Carcase inspection and trim (free from visible physical contamination)	-	-

Inputs	Primary process	Secondary process	Waste streams
-	MLC Weigh and grade	1.18 Carcase stamping (optional)	-
Tote bins	1.43 Kidney removal	1.43.1 Bulk weigh/label	-
-	1.44 Flare Fat gland removal	-	-
-	1.45 Trichinella sample taken (optional)	1.45.1 Trichinella sample transfer to lab, 1.45.2 Trichinella sample testing	-
-	1.46 Half a head (optional)	1.46.1 Flare fat lifting/snow fat removal	-
-	1.47 Fillet drop and trim	1.47.1 Fillet scraping (optional)	-
-	1.48 Carcase misting (optional)	-	-
Hook gambles	1.49 Carcase Rapid chill minus 18 degrees to 30 degrees approximately 1 hour.	1.48.1 Hip/hyper stretch suspension (optional)	-
-	1.50 Carcase chiller Carcass temperature less than 7 degrees in 24 hours, target less than 5 degrees.	-	-

Original generic abattoir process flow chart

Digital twins report: Annex 2 Glossary

Acronym	Definition
AI	Artificial Intelligence
AM	Ante-Mortem
DES	Discrete Event Simulation
FBO	Food Business Owner
FSA	Food Standards Agency
MHI	Meat Hygiene Inspector
MOC	Manual of Official Control
OV	Official Veterinarian
PM	Post-mortem
STFC	Science and Technology Facilities Council
WIP	Work in progress