Woolshed Throughput Improvement Using Discrete Event Simulation

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Abstract:

Purpose: Computer-aided production engineering simulation is a common approach in the search for improvements to real systems. They are used in various industrial sectors and are a basis for process improvement. Such production simulations have found limited use in the wool industry. This study aims to compare the performance of different woolshed layouts (curved vs linear).

Design/methodology/approach: A discrete event simulation is constructed for both considered layouts in Siemens Tecnomatix Plant Simulation software. Data from an in-field observational visit to a working woolshed and industry gray literature is used to validate the simulation model. The two layouts are compared in their base configuration and with equipment and worker changes to evaluate the impacts on throughput.

Findings: In the base configurations, the curved layout reduces total worker travel time which increases production by 11 fleeces per day over the linear layout. The addition of an extra skirting table in the curved layout further increases throughout by 30 fleeces per day. The addition of more wool handlers does not have as large of an impact indicating that processing limits occur due to equipment capacity and shearer speed.

Research limitations/implications: The sample size of the collected field data was small; some data have been collected from literature and not directly measured. Processing time is assumed to be distributed uniformly as a conservative distribution form. The study's purpose is to evaluate relative differences in two different layouts using consistent worker parameters.

Practical implications: This verifies the proposed curved shed layout improves production and gives farmers the ability to compute the long-term economic impact. The results also highlight that other processing stages in the shed need adjustment for more system gains.

Originality/value: As the first application of discrete event simulation to evaluate woolsheds operations this work shows throughput gains are possible with layout, equipment, and worker changes to current practices. Additionally, this work shows the effectiveness of discrete event simulation evaluating woolshed designs. The results can be used to reduce costly experiments.

Keywords: discrete event simulation, digital model, plant simulation, woolshed

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1. Introduction

Computer-Aided Production Engineering (CAPE) is a science of representing a system or process for the intent of evaluation and examination (Barton, Joines & Morrice, 2017). This digitalization process is popular in manufacturing due to its ability to visualize and provide a better understanding of the whole manufacturing process. It is commonly used when planning a new facility or optimizing an existing one to save time, money, and effort by testing proposed ideas and options before implementing them. CAPE has been successful in enabling production evaluation and optimization in several industrial sectors (Florescu & Barabas, 2020). However, it has yet to be widely applied in on-farm agricultural processes due to skillset and access barriers (Gittins, McElwee & Tipi, 2020). In particular, it has not been used in wool handling and shearing sheds. This material flow process can benefit from the well-developed production simulation tools offered in modern CAPE software. In particular, competing shed layouts are evaluated to identify bottlenecks and offer suggestions for system improvement.

Discrete Event Simulation (DES) is a major method in CAPE. DES simulates the behavior of entities when an event happens at a specific point in time. These events are then evaluated over time. It is commonly used to simulate the performance of an actual process, system, or facility (Klingstam & Gullander, 1999). DES has been utilized by several industries such as aircraft manufacturing (Powell, 1999), healthcare (Jacobson, Hall & Swisher, 2006), supply chain management (Kogler & Rauch, 2018), material handling (Bhosekar, Ekşioğlu, Işık & Allen, 2021), and product development (Pérez-Escobedo, Azzaro-Pantel & Pibouleau, 2011) to improve production flow and reduce all forms of waste. This diverse set of applications shows the value of DES as a tool for production and logistics planning. Different approaches to categorizing the areas of application can be found in the literature. Jahangirian, Eldabi, Naseer, Stergioulas and Young (2010) examined 250 studies in simulation, which are assigned to the categories of order planning, inventory management and factory planning, among others. Negahban and Smith (2014) categorize around 290 simulation studies as production system design and planning. These categories can be assigned to the areas of planning and control of production systems (Meyr, Wagner & Rohde, 2015). Semini, Fauske and Strandhagen (2006) note that the focus is on the use of simulation in the semiconductor and automotive industries, however, the literature contains diverse application examples across several industries. Some examples use-cases include:

1. Kampa and Gołda (2018) employed DES to create three models which evaluated changes to a manufacturing system of steel casting foundry. They simulated the replacement of a human workforce with automation and evaluated the work efficacy. The results of the simulation model confirmed the benefits of replacing the manual-operated line with the automated one in terms of throughput, products quality, and production speed.

2. Siderska (2016) used plant simulation to test a model to eliminate wasted time and increase productivity in a bar stool production company.

3. Kliment, Popovič and Janek (2014) used Plant Simulation to analyze production line capacity and explain the effects of individual workstation failures on the efficiency of the whole production line. Also, an experiment was done to determine the lowest number of pallets needed to ensure the maximum use of production lines. The results showed that the elimination of 5% of bottlenecks led to an increase in production by around 5%.

4. Another application specifically for Tecnomatix Plant Simulation software was conducted by Borojevic, Jovisevic and Jokanovic (2009) to introduce a model for crankshaft production and assembly of saw engines. This model helped by identifying bottlenecks, inefficient workstations, and increasing the whole processing time by introducing buffers between workstations to reduce the transportation times. It also recommended extra machines be added to optimize the whole production process.

Thus, simulation studies have been applied in many industrial sectors for various fields of application and in combination with optimization methods for the identification of optimal process parameters. To date, the authors are aware of no such application of DES in the wool industry using DES for production enhancement.

Shearing shed research for the wool industry has focused on human factors and ergonomic design or wool quality metrics. Such ergonomics research seeks to reduce the risk of worker injury due to poor posture and repetitive actions during their work. For example, to reduce lower back pain (LBP) injuries, Harvey, Erdos, Bolam, Cox, Kennedy & Gregory (2002) analyzed different types of shed floor and floor slope to reduce the force required to drag sheep onto the shearing board. Similarly, the effect of using a back harness to support shearers has been studied by Gregory, Laughton, Carman, Milosavljevic and Callaghan (2009), while Milosavljevic, Gregory, Pal, Carman, Milburn & Callaghan (2011) investigated the amount and duration of axially twisted postures on the probability of being affected by LBP. The research concentrated on the factors that contribute toward improving wool quality and quantity, studied the influence of using chemical lice treatments (Niven & Pritchard, 1985), sheep nutrition (Kelly, Macleod, Hynd & Greeff, 1996), and shearing time (Story & Ross, 1960). None of this prior work looks at the flow of material throughout the entire shed.

Shearing shed design not only affects human and animal safety but also plays an important role in the amount and quality of harvested wool. Woolshed designs vary by shearing stand arrangement, board position, and size depending on the number of workers, skirting tables, wool presses, and location of wools bins. Traditionally, wool sheds would conform to a *linear* layout where shearing stands are arranged in a single straight line (Figure 1a). However, recent research from Australian Wool Innovation (n.d.) has proposed an alternative layout, which will be called *curved* (Figure 1b). This research uses DES to simulate the two current competing shearing shed arrangements and compare their performance. These two shed layouts are chosen as the dominate designs in industry.
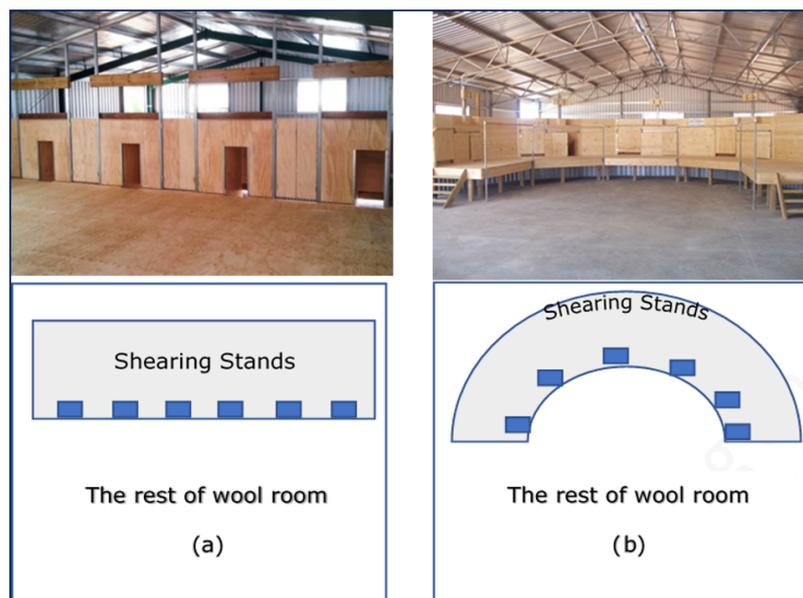

Figure 1. Shearing stands arrangement, (a) Linear layout (Shearing Shed Solutions, n.d.),
(b) curved layout (Kendrick Sheds, n.d.)

2. Methodology

This section describes the steps to build and compare the digital models for both shed layouts. The digital model was defined in a systematic procedure with experimental validation (Figure 2). The objective was defined as identifying the bottlenecks in a manual on-farm wool shed, followed by collecting field data to construct the model then verify and validate the simulation. Once the model was validated, it was used to analyse the bottlenecks and the efficiency opportunities in two proposed shed layouts.

The problem is defined as evaluating which shed layout has the better performance in terms of productivity and resource utilization. Resource utilization was selected as the evaluation criteria.

Data collection is the third step and it is critical in determining the accuracy of the model. Data was collected through direct measurements of an on-farm visit during a typical shearing and wool handling day and supplemented with a review of industry reports and relevant literature.

The following subsections are organized as: an overview of the wool harvesting process in section 2.1, while section 2.2 illustrates wool processing data collection. Modelling of the shearing shed using DES in section 2.3. model verification and validation are presented in section 2.4.
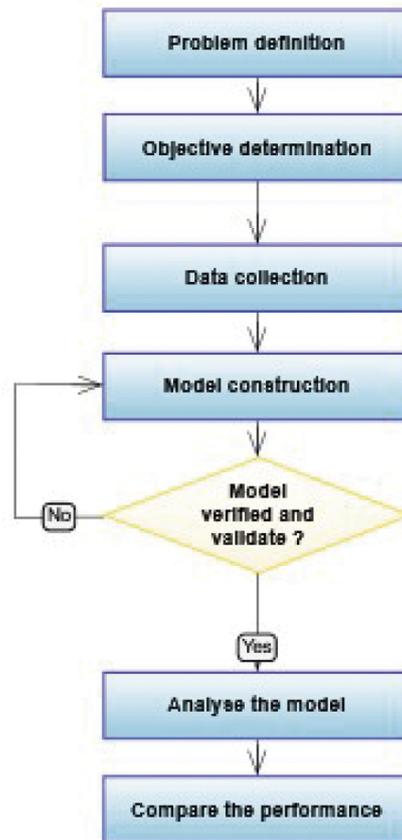

Figure 2. The procedure for building a digital production model (Ruiz-Zúñiga, Urenda-Moris & Syberfeldt, 2016; Ng, Persson & Urenda-Moris, 2008)

2.1. Overview of the Wool Harvesting Process

In general, wool harvesting comprises four main processes (Figure 3): (1) shearing; (2) skirting; (3) classing, and (4) pressing and baling:

1. Sheep are taken from catching bins by workers called *shearers* to the shearing stands. Then the shearers shear them to remove the fleece and small wool cuts.

2. The workers called *wool handlers* gather and collect fleece from shearing stands then pass it to the skirting table. Meanwhile, cleaners sweep the floor and collect short cuts of wool and send it to small bins stationed near the skirting table. At the skirting table, wool handlers carry out skirting, i.e., removing reject wool (soiled, stained, or contaminated) from the rest of the fleece.

3. The worker called a *wool classer* evaluates the fleece and categorizes it into one of multiple classes. Typically, the most valuable or largest volume class is pressed first. Wool that cannot be put in the press immediately is passed to different buffer cages according to its quality (length, strength, color, etc.) based on its designated class.

4. Finally, fleeces are added and pressed in a wool press until the bale reaches the required weight (110-204 kg). A worker called a *wool presser* fastens and seals the bale, then it is taken for labelling and moved into storage.
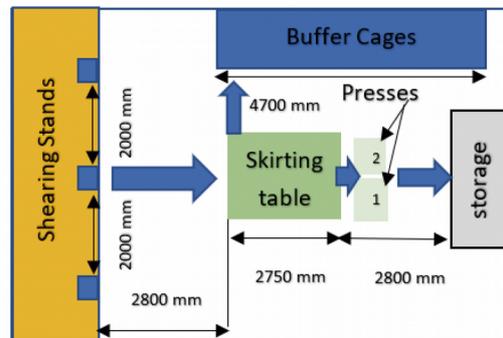

Figure 3. Shed layout overview diagram for the visited shed indicating the four main process areas: shearing stands, skirting tables and presses, buffer cages and final product storage. Workers transport the wool between stages, blue arrows represent fleece movements.

2.2. Wool Processing Data Collection

Field data and industry reported values were combined for the simulation. An actively working woolshed in Bathurst, New South Wales, Australia, was observed and data collected on in-shed wool processing for educational purposes. This data was then used for this project a later stage. The field visit was carried out to this 3-stand shearing shed on 13 August 2020. Figure 4 shows photos of this shed during the shearing and wool skirting processes, respectively. This shed is used as a source of information in constructing the digital model. Observations of the shed were made for 1 shearing session, approximately 2 hours, and recorded in a notebook. The durations of the steps/processes were measured by stopwatch and recorded. Interviews with shed staff were also conducted to ensure the data was representative. The shed contained 9 workers (3 shearers, 2 wool handlers, 1 classer, 1 presser, and 2 floating shed hands), although one staff member more than is typical, it provided useful data on processing speed for each stage and to confirm literature ranges are suitable.

In addition, training materials and literature reported values for shearing, skirting, baling, and pressing times were acquired that were complementary to the shed visit, e.g., conventional shed layout information was collected from the Australian Wool Innovation (n.d.). Measured field data was consistent with industry training materials and published processing times for both individual processes and overall shed throughputs. No tendency toward any particular probability distribution was found in the data.

Figure 4. Shearing stage (left) and skirting stage (right)

2.3. Modelling of the Shearing Shed Using Discrete Event Simulation

To visualize the current production process and compare the performance of the two sheds layouts, a digital model has been developed using a product lifecycle management (PLM) software called Tecnomatix Plant Simulation.

This software was chosen for its ability to provide effective analytical tools such as layout optimization, bottleneck analysis, diagrams for tracking material flow, and statistical data outputs (Siderska, 2016).

The constructed layout was built according to a typical shed's dimensions, collected from its design sheet (Australian Wool Innovation, n.d.). Here the distance between shearers is around 2.3m and the distance between the skirting table and shearing stands is around 6.5m in the curved layout, while the equivalent linear layout is built by adjusting the shearing stands with keeping the distances between shearers fixed.

The comparative study compares two shed designs containing 14 workers (6 shearers, 2 wool handlers, 2 cleaners (or shed hands), and 3 people doing the skirting, with one of them carrying out wool classification and 1 presser). Skirting table, shearing stand sizes and locations were taken from the current common linear layout and the more recently proposed curved layout and modeled (Figure 5). Bins, press, cage (buffer), and store locations and dimensions are arranged according to the observed layout in Bathurst facility.

Figure 5a represents the constructed model built using the PLM software to mimic the real shearing shed. The developed model consists of six shearing stands (arranged in a curve), a skirting table located in the center, surrounded by two bins on each side, two wool presses followed the skirting table, five cages, and stores. While Figure 5b represents the same shed but with the shearing stands arranged in a single straight line, this will be referred to as a *linear* layout.

Worker parameters are assumed constant for both layouts, meaning processing time, recovery time, process variation, skill level, and travel speed are kept constant in both arrangements. The perturbed variable for simulation is the location of shearing stands. Table 1 shows the parameters that were used for workers as input in both layouts. Traveling speed is 1.5 m/s and worker efficiency is 100%.
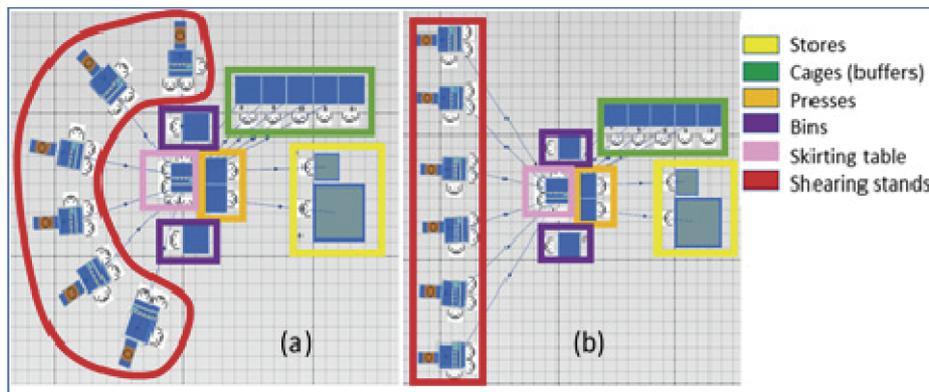

Figure 5. Shed layout in Plant Simulation, (a) Curved, (b) Linear shearing stand arrangement, blue arrows represent fleece movements

	Worker	Amount	Shift	Speed	Efficiency	Additional services	
1	*.Resources.handler	2	Day	1.5	100	handling	swiping
2	*.Resources.shearer	6	Day	1.5	100	shearing	
3	*.Resources.skirtter	3	Day	1.5	100	skirting	
4	*.UserObjects.cleaner	2	Day	1.5	100	cleaning	
5	*UserObjects classifier	1	Day	1.5	100	classifing	pressing

Table 1. Workers' parameters for both layouts in Plant Simulation

The processing and recovery time for the workers measured during the shed visit varied from 2 to 3 ½ minutes depending on the shearer's ability, as well as the sheep's size, temperament, and condition (see Appendix A for the individual measurements). In the model the processing time for the shearers follows a uniform distribution, the minimum and maximum values are varied between the six shearers, while the recovery time is set to one of two

values 10 and 15 seconds. The observed processing time for skirting took between 25 to 28 seconds. For baling, processing time follows a uniform distribution between 2 minutes to 2:30 minutes, while the recovery time was 30 seconds (the mode). Based on these observations, Table 2 shows the data which is used in the model.

After collecting data, two digital models were constructed using Tecnomatix plant simulation, one for each layout as seen in Figure 6.

Process	processing time (min: sec)	Recovery time (min: sec)
Shearing 1	2:30-3:00	0:10
Shearing 2	2:40-3:00	0:10
Shearing 3	2:20-3:00	0:15
Shearing 4	2:30-2:50	0:15
Shearing 5	2:30-3:30	0:15
Shearing 6	2:30-3:00	0:15
Skirting	0:25-0:28	00:00
Balling	2:00-2:30	0:30

Table2. Processing and recovery time for shearing and skirting processes based on the collected data
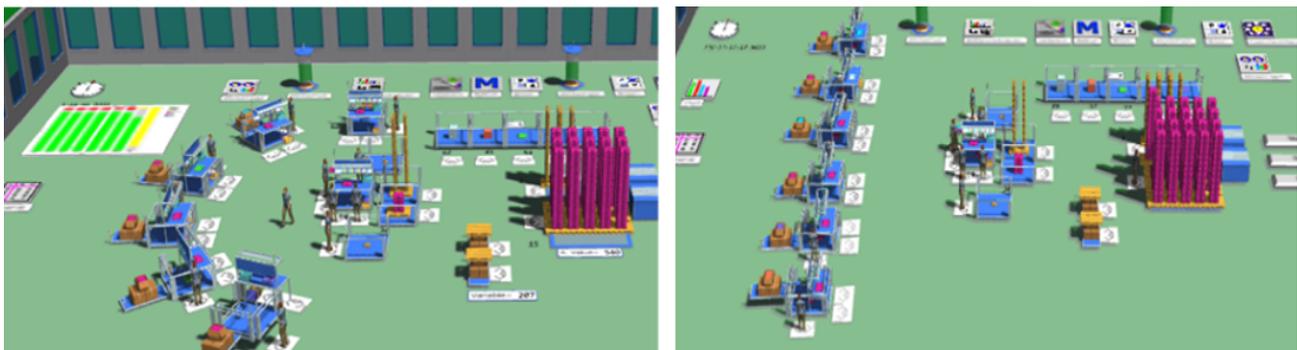

Figure 6. Tecnomatix 3D model for both layouts: curved (left), linear (right)

2.4. Model Verification and Validation

After constructing the digital model, a verification and validation process was applied to make sure that the developed digital models represent the physical model (real-life harvesting process) accurately. Verification is the process of checking that the model is working as programmed and there is no error or bugs occurred in the software. And to check the model in detail at steps during simulation to ensure every resource (worker) is correctly performing their assigned task.

The next step is validation which is the step of comparing the digital model results with the real-life results. To do the validation the amount of produced fleece from the digital model is compared with the real amount obtained from the visited shed in a model that reflects the number of workers and setup in the observed shed. The workers processed 485 fleeces in average. The digital model predicts an average of 478 per day, which results in an acceptable error of 1.4% given the expected variation.

After ensuring the performance and accuracy of the constructed models in the verification and validation stage. The base model was extended to compare the performance between the two target layouts as well as to detect production inefficiencies, such as the bottlenecks. To reduce these production inefficiencies, what-if scenarios were applied in the simulation models. The analysis results and suggested improvements are presented in the next section.

3. Results and Discussion

The model simulates a single workday of 7 hours 40 minutes of working time. According to the processing time for the six workstations within 7:40 hours, the output of the production line was 826 fleeces in the curved layout and 815 fleeces in the linear layout. Statistical analyses of work at each workstation executed at the end of the production process showed that this difference is a consequence of an increase in the shearers being blocked by the skirting table, as indicated by the increased yellow portions in Figure 7b, compared to Figure 7a.

Figure 7 also shows that the working percentage for the skirting table was 79.06% and 78.04% for the curved and linear layouts, respectively. As well as there was some blockage in the skirting process in both layouts 4.11% (curve), and 4.22% (linear), the reason behind this is the baling process. Which stops the flow of skirted fleece from buffering inside of the press. This occurs after the bale is has reached the weight limit and while it is being unloaded and a new wool pack (bag) is inserted.

A deeper look at the statistical results showed that the output of the curved layout is improved due to the wool handlers traveling shorter distances overall throughout the working day. Table 3 illustrates the total travelled distance by cleaners and wool handlers in each layout. The workers experience approx. 30% drop in distances travelled with the curved shed layout, meaning they are more often ready to receive fleeces from the shearer and deliver them to the wool table without delays. In a real shed, this has an added benefit of reducing worker effort by limiting their walking distance, which supports the human factors intention of the *curved* design.

Despite the curved layout reducing blocking, both layouts still suffer from a bottleneck created by the skirting table. Figure 7 shows the blocking percentages and blocking time for each layout.
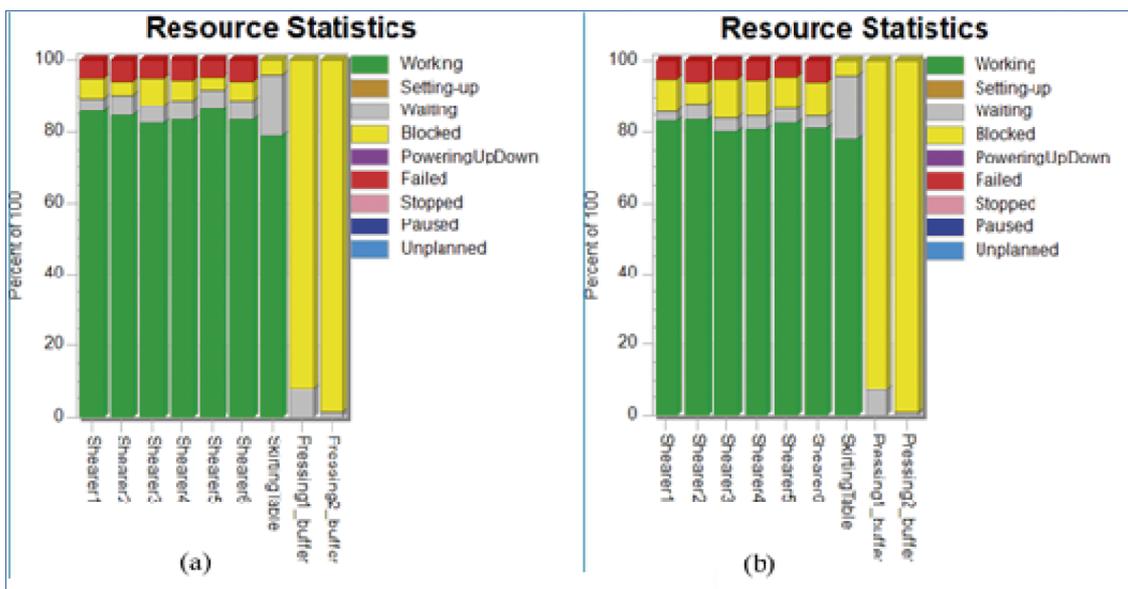

Figure 7. Resource statistics from Plant Simulation model for (a) Curved shed layout, (b) Linear shed layout

Worker \ Layout	Linear (m)	Curve (m)
Cleaner1	6018	4275
Cleaner2	10081	7127
Wool handler 1	8191	5865
Wool handler 2	8841	5893

Table 3. Travelled distances by workers in each layout

The suggested solutions to increase productivity are a) adding another skirting table, b) adding extra wool handlers, or c) reducing the skirting table processing time. These scenarios have also been analyzed on the curve layout.

First solution suggestion: add another skirting table (Figure 8a). The simulation model for this solution showed satisfying effects, as it raised the production to 856 fleeces of wool within 7:40 hours. The blocking percentage and blocking time in the curved layout after this addition decreased. This makes the shearers work near full capacity, as shown in Figure 8b. However, some blockage at the shearing stations can be noticed after adding an extra skirting table and the reason behind this is the variability of wool handlers' arrival rate and the service rate variability at the skirting table. In general, adding a buffer between the skirting table and the shearer stations could be a solution to manage variability issues, but wool handling requires specific handling methods that make this infeasible. Fleeces must be passed to the skirting table directly and without mixing with other fleeces. So, carrying the fleece again from the buffer and to the skirting table would consume more time due to the extra handling and may reduce quality by spreading contaminants.
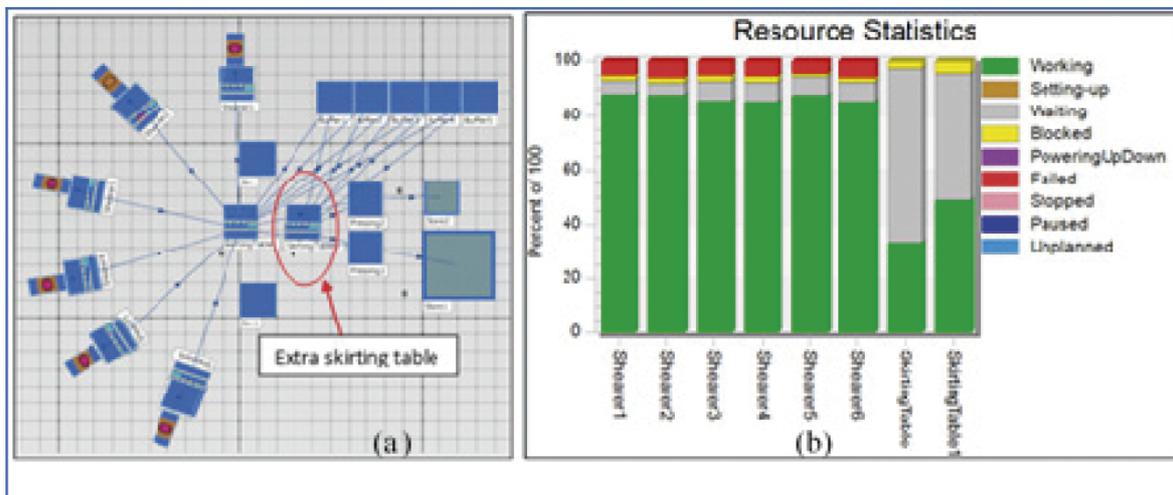

Figure 8. Plant Simulation model showing the curved wool shed layout
with two skirting tables and accompanying resource statistics

The next simulated solution: add extra wool handlers. To evaluate This solution five experiments were applied. The number of wool handlers was increased from 2 to 6 workers. A proportional relationship was observed between the number of wool handlers and the output up to a saturation point. The maximum number of produced fleeces in this case when the system has 6 wool handlers was 833 as shown in Table 4. The first solution of adding a skirting table showed better results, and the additional worker(s) add more cost than the small increase in fleece is worth.

Number of wool handlers	Number of fleece (curve)
2	826
3	827
4	828
5	833
6	833

Table 4. the second scenario adding extra wool handlers

The last scenario is reducing the processing time of the skirting table by adding a worker to do the skirting or by automating the process. By utilizing DES, a set of thirty-one (31) experiments were simulated for a range of skirting processing times (10-40 sec). The results shown in Figure 9 illustrate the optimal processing time that

provides the maximum operation time and maintains the highest throughput was 22 seconds which yields an output of 868 fleeces per day. This processing time ensures the shearers are not blocked as shown in Figure 10, maximising utilization.
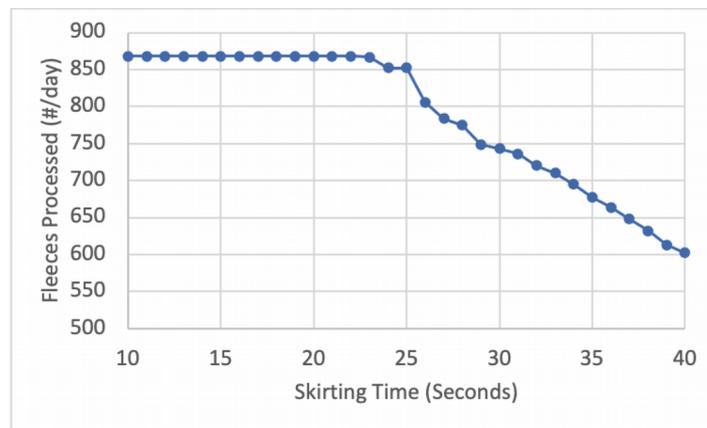

Figure 9. Number of shorn fleeces according to skirting table processing time with the optimal speed highlighted in blue
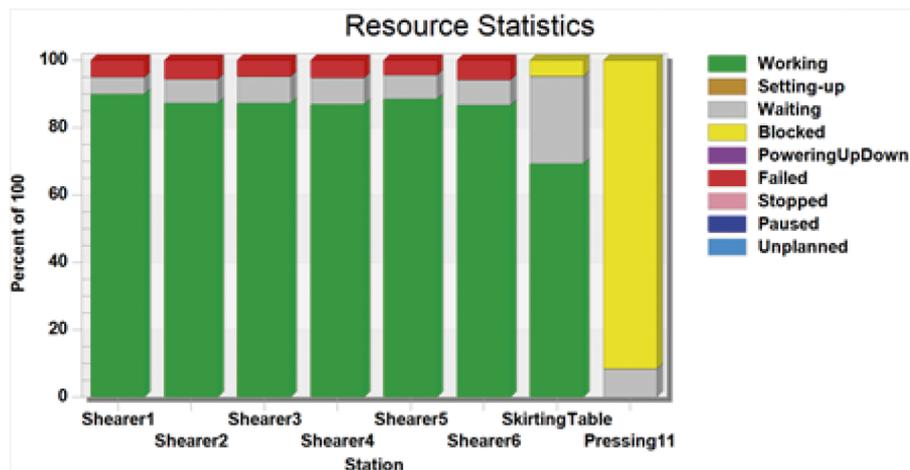

Figure 10. Resource statistics for skirting process time equal to 22 seconds

DES provides a straightforward and low-cost route to generate and evaluate potential solutions for the bottleneck. The associated layout changes show an increase in employee productivity and thus an increase in the output of the production system. Processing times are assumed to be uniformly distributed. This choice reflects the small sample size of the experiment not demonstrating a clear distributional form and provides convergence to a normal distribution should a sufficiently large simulation be performed. This property makes for a conservative estimate on the process variability with the limited data.

4. Conclusion

This study used discrete event simulation to compare the performance of different wool shed layouts (curved vs linear) and evaluate solutions to improve shearing shed performance. This is the first study of this problem for wool handling to improve production. The digital model revealed that the curved layout showed better performance than the linear layout. Specifically, the curved layout showed better performance than the linear layout by an increase in output of 11 fleeces over a one-day working period (equivalent to 33 min saving). The underpinning reason was the reduction in travelling time for workers in the curved layout, which helped to reduce the blocking at the skirting table. Several scenarios were explored to improve the production in the curve layout. Adding a second skirting table decreased the blocking problem. That meant the shearers could work near

their full capacity, leading to an improvement in the throughput, this enhanced production from 826 to 856 fleeces. A second scenario of increasing the number of wool handlers' number showed that only a small gain was possible with the highest throughput of 833 with an extra four handlers. Finally, the best possible scenario was reducing the processing time for the skirting table to 22 seconds resulting in higher productivity reaches to 867 fleeces.

The paper shows how improvements in this industry can be identified and evaluated using DES. Through further simulation-based investigation of the wool harvesting process, an optimized production layout could be designed and examined with regard to its potential for improvement. This approach eliminates the need for costly planning, which is usually associated with high investment costs.

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Appendix A

Field data for three shearers and skirting through using stop watch and supplementary data extracted from industry literature

Shearer	Shearing speed 1	Shearing speed 2	Shearing speed 3	Shearing speed 4	Recovery time
Shearer 1	2:30-3:00 (RSPCA Australia, n.d.)				10
Shearer 2	2:40	2:43	2:54	3:00	0:10,0:12,0:10,0:09
Shearer 3	2:20	2:27	2:48	3:00	0:12, 0:15, 0:15, 0:14
Shearer 4	2:30	2:35	2:42	2:50	0:15, 0:15, 0:15, 0:14
Shearer5	2:30-3:30 (Australian Wool Innovation, 2015a)				15
Shearer6	2:30-3:00 (RSPCA Australia, n.d.)				15
Skirting	0:25, 0:25, 0:28, 0:26				0:00
Balling	2:00-2:30 (Australian Wool Innovation, 2015b)				0:30 (Australian Wool Innovation, 2015b)