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Productivity Improvement Based on the Theory of Constraint and Eliminate, Combine, Rearrange, Simplify for Chilled Beef Production in Indonesia

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Abstract
This paper aims to enhance the productivity of a chilled beef production line by comparing two techniques; standard time calculation and simulation. The best improvement method was obtained using the work-study principle, a network diagram, and bottleneck identification. Two methods for improvement are proposed based on the ECRS, the Theory of Constraint (TOC), and line balancing concepts. A simulation model is developed to mimic the actual production line. The simulation results are verified, validated, and compared. Some workstations were combined, and the allocation of the workers was arranged. The present production line efficiency was 46.21%, which increased to 67.09% and 79.71% from the suggested methods. It showed that using the standard time calculation gives a different result from the simulation. In summary, the simulation model along with the application of TOC and ECRS, provides accurate information and improves overall productivity.

Keywords
Work study; ECRS concept; TOC; Line balancing; Monte Carlo simulation.

Introduction

Beef is one of the considered livestock supplies in Indonesia. It is the second supply of animal protein (21.27%) after chicken (58.02%) (Komalawatia et al., 2019). Indonesia's average individual beef consumption was about 1.98 kilograms per year in 2019 (Hirschmann, 2020). The beef consumption projection will increase to 2.79 kilograms per capita per year in 2025 (Arifin et al., 2018). In 2045, the beef consumption projection will be raised to 3.04 kilograms per capita per year. The domestic beef production in 2016 was 524,000 tons, while current consumption is estimated at 650,000 tons. The Indonesian demand for beef is fulfilled through three supplies: local production, imported live cattle, and imported meat (Chang et al., 2020). Due to a shortage of certain products, the government has permitted the importation of frozen meat and live cattle, predominantly from Australia, to meet the demand (Agus & Mastuti, 2018).

The demand for beef is high in most big cities and urban areas. The beef is still considered an attainable luxury item for the middle and upper classes. Numerous variables, such as population and economic expansion, as well as Indonesians' growing understanding of the value of protein for health, impact the country's rising demand for beef (Komalawatia et al., 2019); Agus et al., 2014).

The beef trade in Indonesia involves many stakeholders, including importers, feedlots, abattoirs, traders, warehouses, third-party logistics providers, and retailers (Antara & Sumarniash, 2019). The fast-moving nature of perishable goods raises concerns about changes in the food supply chain, including the handling, storage, packaging, distribution, and technologies used to monitor the entire process. These factors contribute to more complex supply networks and

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highlight the importance of logistics in efficiently obtaining the product from the farm to the consumer's table (Tsai & Pawar, 2018). Therefore, managing the cold chain becomes crucial to preserve the freshness and guarantee beef quality before arriving at the consumer (Nastasijevic et al., 2017). A case study company is an abattoir providing cattle slaughter and production services. The company has served Indonesian markets, such as HORECAs and supermarkets, since 2005. The company intends to generate a final product from high-quality cattle that satisfies Indonesia's national standard. One of Indonesia's more modern slaughterhouses, this business produces and processes chilled beef, frozen beef, and portions of goods in response to consumer demand. Meanwhile, other local business enterprises will receive the side goods, which include meat offal, fat, skin, and bone. The Australian cattle that were brought and will be butchered had spent 100 days being fattened in Lampung Province. Each week, on average, 150 cattle are butchered. The Java and Bali Islands will receive the final product. In addition, this company also serves some frozen lamb chops from Australia. The frozen lamb chops will be imported according to customer demand.

Most slaughterhouse businesses mainly require human labor since the processes are still performed manually. Therefore, labor or workforce costs are among the highest costs in any industrial production line. When there was overtime, the company had to pay the overtime to the workers, which could reduce the company's profit. The workforce's determination of balance time activities analysis is needed to maximize the labor and obtain the proper balance of the production line (Fernandes Junior & Pinto, 2020). This study aims to enhance the productivity of a chilled beef production line by comparing two techniques: time study by combining the theory of constraints, line balancing, and ECRS methods and a simulation. In a long term, we wish this case study could serve as a model for other food companies to increase productivity and benefit Indonesia's food business. The structure of the research was outlined, starting with the significance of the beef industry in Indonesia in the introduction section. The literature review section covered related research on work study, the theory of constraints, line balancing, and ECRS methods, as well as simulation. The methodology section described the investigation of the current production line, the process improvement plan, and the building of the simulation model. The results and discussion section presented the analysis and comparison of the process improvement results. Lastly, the conclusion section highlighted the unique aspect of the research, its achievements, findings, contributions, and potential future research directions.

Literature review

One of the most significant expenses in any business is the labor cost for the production process. In order to optimize workforce usage and achieve proper balance, it is essential to analyze the time spent on worker activities to determine the process balance (Fernandes Junior & Pinto, 2020). Work study involves examining a job to determine the most efficient way to do it and to establish a standard time for completing it using that method. In other words, a work-study aims to analyze the way an activity is performed, identify opportunities to simplify or modify the method to eliminate unnecessary work or resource waste, and set a standard time for completing the activity (Duran et al., 2015; Gujar & Moroliya, 2018).

Work study involves both motion and time study. It analyzes and improves work techniques by considering all factors that impact work efficiency and conditions (Pisuchpen & Chansangar, 2014). The steps listed below should be followed to perform a time study: jot down all relevant task data, segment the work into smaller components, evaluate the current components, calculate the sample size, record the cycle times for each component, estimate the working speed, convert the observed time to normal time, calculate the allowance, and establish the standard time. Finding the most effective way to distribute tasks among workstations on an assembly line to satisfy precedence relations and maximize particular performance metrics is known as "line balancing." Line balancing aims to optimize the capacities and flows of the manufacturing processes by positioning the personnel or facilities in the most effective way feasible. One essential line-balancing technique minimizes the balance delay or the number of workstations required (Manaye, 2019). In many food processing plants, the time it takes to complete a production cycle is influenced by the speed at which workers work, the speed of the machines, and the speed of the conveyors. In an assembly line, certain stations are responsible for specific tasks. Line balancing was developed to be economical while producing standardized goods in large quantities (Chueprasert & Ongkunaruk, 2015).

The Theory of Constraints (TOC) is an area of ongoing development and growth that warrants further investigation (Ikeziri et al., 2018). According to the TOC, manufacturing processes are viewed as "chains," in which the strength of the entire system is limited by its weakest link (Rajini et al., 2018). The goal of the Theory of Constraints (TOC) is to identify the weakest link (constraint) in an organization and to address it to remove it as a barrier to the overall strength of the chain (organization) (Pegels & Watrous, 2005). Constraints can be physical resources or policies limiting the organization's ability to achieve its goals (Ehie & Sheu, 2005). TOC comprises several concepts, including thinking process tools, performance assessment systems, and operations planning tools (Umble et al., 2006). TOC can be summarized as two main points: (i) There must be at least one limitation or constraint in every system., and (ii) the presence of constraints indicates chances for improvement (Rahman, 1998). The traditional approach to the Theory of Constraints (TOC) in a stochastic setting may not be optimal. In this case, it is urged to consider the bottleneck throughput of various types of machines at the planning stage (Yan et al., 2019). Lean Manufacturing (LM), which originated from the Toyota Production System (TPS), is a widely recognized method for reducing waste in production through the use of tools such as value stream mapping and balancing the workload of the production process (Fernandes Junior & Pinto, 2020). Two combination approaches were examined: Value Stream Mapping (VSM) and Thinking Process – Theory of Constraints (TP-TOC). It was discovered that VSM helps to organize the production process and identify inefficiencies in its implementation.

Meanwhile, TOC aids in analyzing the production process from various angles (Pereira Librelato et al., 2014). TOC is an approach to operational excellence that helps managers and practitioners address the complexities and potential challenges in supply chain operations (Mangla et al., 2020). The operation strategy related to the Theory of Constraints (TOC) context was expanded to more accurately assess the impact of TOC elements on competitive priorities such as on-time delivery, responsiveness, and resilience (de Jesus Pacheco et al., 2020).

Eliminate, Combine, Rearrange, and Simplify (ECRS) is a method used in motion study to improve a production line (Kasemset, 2014). The ECRS method is based on the following core principles: 1) E –Eliminate unnecessary tasks, 2) C – Combine multiple operations, 3) R – Rearrange the operation sequences, and 4) S – Simplify the necessary operations. Many agro-industrial plants are labor-intensive, meaning task times can be uncertain due to factors such as employee skill level, working environment, health, weariness, along with others. ECRS can decrease waiting times at stations other than the bottleneck when task times change, lowering labor costs and boosting productivity (Ongkunaruk & Wongsatit, 2014). By improving processes, a company can increase its efficiency, effectiveness, productivity, and customer service levels (CSL) (Kumar & Phrommathed, 2006).

Simulation entails building a mathematical or logical model of the system or problem and testing it to comprehend a system's behavior and resolve a decision problem. There are two types of simulation models: static and dynamic. They are employed to simulate the long-term dynamics of the actual supply chain. The simulation's outcomes enable an analysis of the supply chain's responses under various circumstances (Evans & Olson, 2001; Jbara, 2018).

Four primary, iterative, and connected components make up the simulation process, and they are ((Yassine et al., 2019): 1) System identification: The system is defined in this step, and the data required to replicate the system is gathered. Production numbers, task descriptions, ordering relationships, and bottleneck operations are possible examples of this data. Before determining the takt time, the task time for the chosen process is also recorded. 2) Model design: Before using the system to simulate, the tools and structure of the models are proposed in this step. A probability distribution is used to describe the input data as a random variable in the simulation. 3) Model execution: The constructed model is run to track its development in this step. 4) Execution analysis: Following the tests' conclusion, the model's data is explicitly examined in this stage. The most straightforward analysis involves only looking at the data and making inferences from it.

Simulation helps to address issues in assembly lines that are affected by the impact of variable operating times due to the variability of the operations, leading to an increase in the overall average production time (Das et al., 2010). A case study involving the use of the Theory of Constraints (TOC) with simulation, Process Based Costing (PBC), and Data Envelopment Analysis (DEA) in a PVC production line found that the implementation of TOC helped to alleviate the constraint and simulation helped to identify the bottleneck process (Shurrab et al., 2017). In a furniture manufacturing production line, the bottleneck was eliminated using a simulation-based heuristic method based on the Theory of Constraints (TOC) concept to balance the flow of semi-finished materials. This resulted in an average production increase of 88% (Gundogar et al., 2016). In a production line that relies on manual labor, the proposed simulation model can optimize each workstation's allocation to achieve better line balancing and maximize the number of workers needed at each workstation (Fernandes Junior & Pinto, 2020).

Methodology

Investigation of the present production line

The task descriptions, linkages between tasks, and bottleneck activities were all identified through analysis of the production process. Several times, the cycle time for each operation was recorded. Then, the line efficiency, takt time, normal time, standard time, and optimal worker count were computed (Ongkunaruk & Wongsatit, 2014).

Process improvement

The process improvement involved implementing the ECRS method to eliminate unnecessarily, combine, rearrange, and simplify tasks. The line balancing concept was also implemented to adjust the processing time at each station by adding or removing resources (people or machines). The total processing time was then calculated using the average processing time for each process.

Simulation model building

A Monte Carlo simulation model was created to mimic the actual production system. The processing time distribution at each step was analyzed, and its distribution was determined for the most accurate simulation. The model was then simulated in a Microsoft Excel spreadsheet. A macro process was developed to calculate the total processing time with 100 repetitions.

Model verification and validation

The simulation results were compared to the actual data in each operation to ensure that the simulated time accurately reflects the production time. The paired t-test was then performed to determine if the simulation was verified and valid.

Simulation output analysis

The simulation output was examined to determine the ideal production model so the productivity of the production line would increase. The outcome of the process improvement of the time study and the simulation output were then compared. The research framework is shown in Fig. 1.

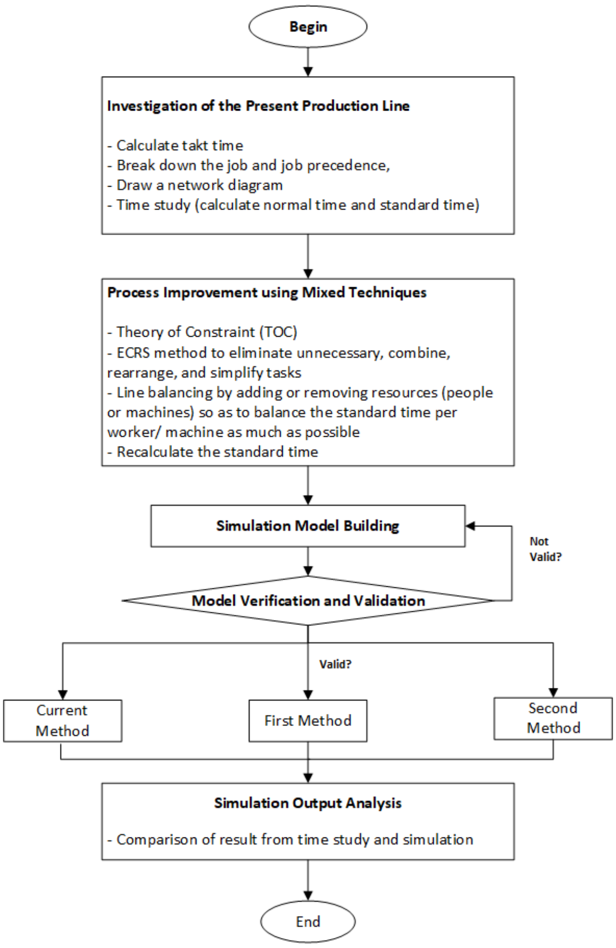

Fig. 1. Research framework

Results and discussion

Analysis of the company

An investigation into the production process revealed that low responsibility among the workforce continues to impact productivity due to a lack of strict regulations. This low responsibility manifests as extended break times during production and unnecessary absences. On the second day of the boning process, workers must work overtime to complete their tasks, sometimes working more than the allotted 7.5 hours per day. Improvements are necessary to reduce the amount of overtime required and decrease the working hours of the workers at the abattoir (Neisyafitri & Ongkunaruk, 2020).

This research focuses on the production line from the bagging process to the final product check. The chilled beef is boned and placed in a plastic bag inside a plastic box, then moved along the production line using a manual roller conveyor. The beef is then vacuum sealed, and the plastic bag is trimmed using scissors. The vacuumed beef is then shrunk in a shrinking tank with water at a temperature of approximately 84°C. After the chilled beef is shrunk, it is sorted by type. The labeling process begins with a worker checking the type of item, placing it on a weighing scale, and entering the item code into a computerized system. The weight data is recorded, and a label is printed and attached to the secondary corrugated fiberboard packaging. The labeled product is pushed to the final checking station via a manual rolling conveyor. The worker who does the last round of inspection counts the objects and ensures they are free of impurities like hair, dust, excrement, and other filth. The worker also checks for any leaks in the vacuum seal. If the items pass the final check, they are sent to the warehouse for storage via an automated belt conveyor. The units used were packed per second, as the processing time for each item was the same.

Study of the current production line

The number of replications was calculated based on (Freivalds & Niebel, 2008), there were 73 replications in total. As a result, 75 replications at each station were performed. The average cycle time for the 11 chilled beef production line jobs was calculated using the recorded data and presented in Table 1.

After observing the production line, the total cycle time for the operation was found to be 91.20 seconds. The takt time is the time needed to meet customer demand within a certain period. In this case, the total customer demand is 1,400 packs per day, or approximately 16,800 packs per month, as there are 12 days of production time. The abattoir operates one shift daily, lasting 7.5 hours, including 1.5 hours of break time. The takt time can be calculated using the formula: Takt time = 15.43 sec/pack. The machine breakdown allowance is 5%, so the adjusted takt time is 14.66 sec/pack. This value is then compared to the bottleneck cycle time. If the adjusted takt time is less than the bottleneck cycle time, the manufacturer will not be able to meet customer demand without working overtime (Ongkunaruk & Wongsatit, 2014). Therefore, it is necessary to improve the production line so that the bottleneck cycle time is shorter than the adjusted takt time.

In the current production line, jobs G, H, I, and J are completed at the same workstation by the same worker. This is depicted in the network model of the current chilled beef production line in Fig. 2.

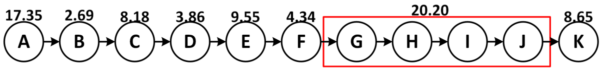

Fig. 2. Network model of the present chilled beef production line

The normal time for each job was determined by collecting data and analyzing it at a 95% confidence interval. According to Salvendy (2001), an allowance of 6% was added for good skill, 5% for good effort, 0% for average environment, and -2% for fair consistency, resulting in a total allowance of 9%. Using the recorded average cycle time per worker at each station, the normal time, standard time, and cycle time per worker/machine were calculated, as shown in Table 2.

Table 1
Cycle time in the chilled beef production line

Station	Job	Explanation	Job precedence	Average cycle time (sec)
1	A	Bagging	–	15.92
2	B	Filling the machine with chilled beef	A	5.2
3	C	Vacuum sealing	B	15
4	D	Handling vacuum-chilled beef	C	7.46
5	E	Shrinking	D	8.76
6	F	Sorting vacuumed chilled beef	E	8.38
7	G	Weighing	F	6.98
8	H	Recording	G	8.02
9	I	Printing	H	2
10	J	Labelling	I	6.2
11	K	Final inspection	J	7.28
			Total	91.2

Table 2
The standard time for chilled beef production with the present production line

Station	Job	Reps	Avg. cycle time (sec)	Rating factor	Normal time (sec)	Std. time (sec)	No. of workers	No. of machines	Cycle time per worker/machine (sec)
1	A	50	15.92	1	15.92	17.35	1	–	17.35
2	B	70	5.2	0.95	4.94	5.38	2	–	2.69
3	C	75	15	1	15	16.35	–	2	8.18
4	D	50	7.46	0.95	7.087	7.72	2	–	3.86
5	E	50	8.76	1	8.76	9.55	1	1	9.55
6	F	50	8.38	0.95	7.961	8.68	2	–	4.34
7	GHIJ	50	18.58	1	18.58	20.25	1	1	20.25
8	K	50	7.28	0.95	7.9352	8.65	1	–	8.65
					Total	93.94	10	4	74.87

It was discovered that the bottleneck cycle time was in station 7 (Job GHIJ), which was longer than the takt time. This means that overtime is needed to complete the task. The total production time for 1,400 packs was estimated to be $74.87 + 1399 \cdot 20.25 = 28,404.62$ seconds or 7.89 hours. The current line efficiency was 41.79%, and the perfect worker count was 6, 4 less than the actual number of workers used. This suggests that the current production line is inefficient and requires improvement.

Process improvement by work study

The suggested improvement was implemented using the theory of constraints, which involves identifying the bottleneck operation. The line balancing method and the ECRS concept (Eliminate, Combine, Rearrange, Simplify) were then utilized to enhance the improvement. This was accomplished by removing any extra people or equipment, grouping numerous tasks into one station, changing the structure or workforce composition at each station, and streamlining the procedure. The line balancing concept was also applied to ensure that the cycle time per worker or machine was consistent across all stations.

The first improvement

Jobs B, C, and D were consolidated into a single station at station 2 in the initial approach. Two workers were assigned to complete jobs B and D, while two automatic vacuum sealing machines performed job C. This allowed for the reduction of two workers at this station. Then, jobs E and F were combined and completed by two workers at one station. Then, a worker from job F was moved to finish jobs G, H, and J, which a single worker had previously handled. Figure 3 displays the network model for the first proposed technique. The overall standard time was 91.53 seconds after the modification, the worker cycle time was 58.21 seconds, and the bottleneck cycle time was decreased to 17.35 seconds. The total production time for 1,400 packs was estimated to be 6.76 hours, which still requires overtime. The production line efficiency increased to 67.09%. In the first improvement, two workers were eliminated, resulting in a reduction in labor costs. However, the bottleneck cycle time was longer than the takt time, indicating that further improvement is needed. Table 3 displays the first method's normal time, standard time, operator count, and cycle time per worker.

Table 3
The first method's normal time, standard time, operator count, and cycle time per worker

Station	Job	Avg. cycle time (sec)	Rating factor	Normal time (sec)	Std. time (sec)	No. of workers	No. of machines	Cycle time per worker/mc (sec)
1	A	15.92	1	15.92	17.35	1	–	17.35
2	B, C, D	27.66	0.95	26.28	28.64	2	2	14.32
3	E, F	17.14	0.95	16.28	17.75	2	1	8.87
4	G, H, I, J	18.58	1	18.58	20.25	2	1	10.13
5	K	7.28	0.95	6.92	7.54	1	–	7.54
				Total	91.53	8	4	58.21

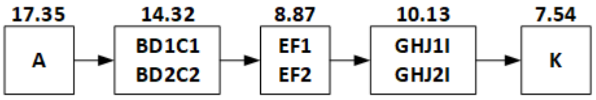

Fig. 3. Network model of the first improvement

The second improvement

This method focused on reducing the bottleneck cycle time from the first method, which occurred in job A. An additional worker was assigned to this station to balance the production line. In addition, as in the first proposed method, jobs B and D were completed separately by different workers to reduce waiting time, and jobs E to J were rearranged to improve efficiency. The network model is shown in Fig. 4. After the second improvement, the total number of workers increased to 9, the total standard time was 92.35 seconds, and the total cycle time per worker was reduced to 56.50 seconds. The bottleneck cycle time was also reduced to 10.13 seconds, shorter than the takt time, eliminating the need for overtime. The total production time for 1,400 packs was estimated to be 3.95 hours. The line efficiency increased to 79.71%. Table 4 displays the second method's normal time, standard time, operator count, and cycle time per worker.

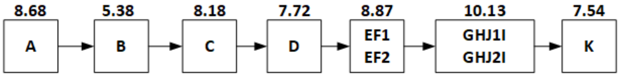

Fig. 4. Network model of the second improvement

Monte Carlo simulation using Microsoft Excel spreadsheet

The work-study explored in the previous section used the average time to estimate the total cycle time. On the other hand, a Monte Carlo simulation model was proposed in this section to simulate the current production line. Then, the results were compared with the work-study method. A spreadsheet was created to simulate the current production line. A simulation model is suitable for the decision maker when the production line cannot be adjusted easily for improvement (Ongkunaruk & Wongsatit, 2014). Initially, the processing time data distribution was determined using the Input Analyzer feature in the ARENA program. This feature also displays statistical information and performs Chi-Square Goodness of Fit tests on the data. This helps to ensure that the input data, which includes inter-arrival time and service time, accurately reflects the actual processing time. The following are the hypotheses for the input data. H0: The processing time distribution is independent and identically distributed (iid). H1: The distribution of processing time is not iid. The processing time presumptions were examined at the 95% confidence level. H0 is accepted, and the data distribution in each workstation is identified if the P-value of the statistical test result is more significant than 0.05.

The simulation model was then developed using a Microsoft Excel spreadsheet. The output data includes the service beginning time, service ending time, and total time in queue formulated based on the processing time distribution for each job, the relationship of time in each station, and the sequence of the job and worker. After verifying the model, the program was run for 100 replications. The resulting output includes the average time in queue, utilization of workers, average service time in the system, and total time for each job in the simulation of the existing production system.

After simulating the current production line, the total time to process 1,400 packs of chilled beef was 7.91 hours. The jobs with the highest average time in the queue were A and G, indicating a lack of resources

Table 4
The second method's normal time, standard time, operator count, and cycle time per worker

Station	Job	Avg. cycle time (sec)	Rating factor	Normal time (sec)	Std. time (sec)	No. of workers	No. of the machines	Cycle time per worker/mc (sec)
1	A	15.92	1	15.92	17.35	2	–	8.68
2	B	5.2	0.95	4.94	5.38	1	–	5.38
3	C	15	1	15.00	16.35	–	2	8.18
4	D	7.46	0.95	7.09	7.72	1	–	7.72
5	E, F	17.14	0.95	16.28	17.75	2	1	8.87
6	G, H, I, J	18.58	1	18.58	20.25	2	1	10.13
7	K	7.28	0.95	6.92	7.54	1	–	7.54
				Total	92.35	9	4	56.50

Table 5
Excel simulation result of the current production line

Job	A	B	C	D	E	F	G	H	I	J	K
Number of workers	1	2	–	2	1	2	1				1
Number of machines	–	–	2	–	–	–	–	–	1	–	–
Avg. time in queue (min)	62.19	0.00	0.09	0.00	0.00	0.00	85.10	0.00	0.00	0.00	0.00
U. of worker/machine	1.00	0.41	0.58	0.18	0.45	0.25	0.90	0.90	0.10	0.90	0.36
Avg. service time in system (sec)	12.94	5.20	15.00	4.51	5.74	6.37	7.00	8.03	2.00	3.23	7.27

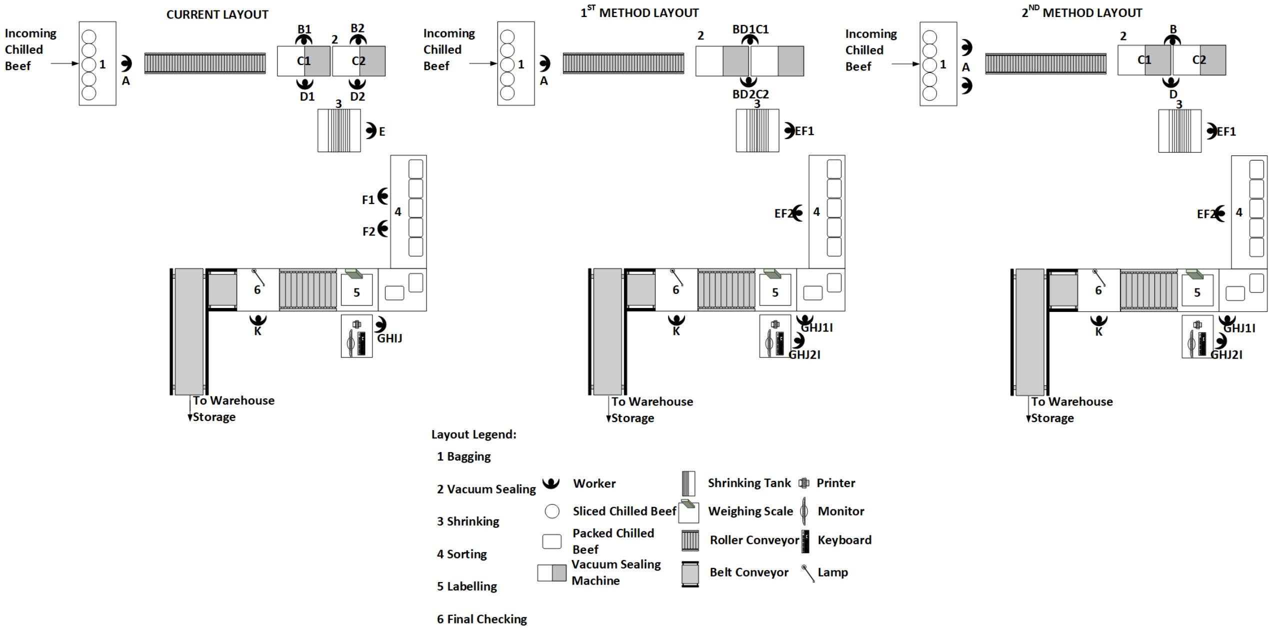

Fig. 5. Production line layout comparison between the current, the first, and the second proposed methods

for these jobs. This is reflected in the high utilization of workers in jobs A, G, H, and J. The utilization of workers in jobs B, D, E, and F was low, suggesting an opportunity to consolidate workers in these jobs. The Excel simulation results of the current production line are shown in Table 5. A comparison of the present, first, and second proposed method production layouts are shown in Fig. 5.

The simulation model's verification and validation

Once the simulation model of the current production line finished running, verification and validation were performed. Verification involved ensuring that the formulas in the Excel spreadsheet accurately represented the actual system to ensure that the simulation would run correctly. The system validation compared the existing system's total time and the simulation system's output. A mean comparison hypothesis test was run at a significance level (α) of 0.05. The outcomes demonstrated no appreciable difference in the total time between the simulation and existing systems. The existing system and the simulation model had times of 91.20 and 91.29 seconds, respectively, with a 95% confidence interval ranging between 86.64 and 95.76 seconds. In summary, the simulation was found to be valid.

Simulation of the first proposed method

The first model was created in a spreadsheet, resulting in a total processing time of 5.04 hours for 1,400 packs. This differed from the ending time calculated from the work-study, which was 6.76 hours, or about 25.44%. The average time in queue for job A was about an hour, indicating the need for an additional worker in this station. Consolidating workers in jobs B and D, as well as jobs G to J, increased the average utilization of workers. However, the average worker utilization was still 0.56, suggesting the possibility of reassigning different workers for jobs B and D, as proposed in the second proposed method. The simulation results for the first proposed model can be seen in Table 6.

Simulation of the second proposed method

In summary, the simulation results of the three models show that the second method is the most effective in reducing the total time needed to process 1,400 packs of chilled beef items. It also has the lowest time in the queue and the highest utilization of workers. These improvements can be achieved by adding one more worker to job A and consolidating jobs B and D and jobs G to J. These changes can help to reduce the reliance on overtime and increase efficiency in the production line, as shown in Table 7.

Results comparison

In this research, the ECRS concept was applied to the chilled beef production line to improve efficiency and reduce waste. The process was improved by removing extra workers or machines, grouping several tasks into one workstation for group projects, changing the structure or make-up of the workforce at each station, and streamlining the procedure. The outcomes demonstrated that the second suggested strategy was the most efficient in cutting the overall production time and raising line productivity. By implementing the second proposed method, the total production time was reduced by 46.59% compared to the current production line, and the line efficiency was increased by 79.71%. This implies that the second proposed method can significantly improve the chilled beef production line.

The line balancing concept is often used in conjunction with the theory of constraints, which identifies the bottleneck or limiting factor in a production process and focuses on improving that factor to increase overall efficiency (Chueprasert & Ongkunaruk, 2015). When applied together, the ECRS and line balancing concepts can help a company optimize its production process and improve efficiency. This means that the bottleneck station's cycle time determines the production line's overall production rate. By reducing the cycle time of the bottleneck station, the overall production rate can be increased. To effectively reduce the cycle time of the bottleneck station, it is crucial to identify and address the root causes of the bottleneck. This may involve improving the efficiency of the equipment or processes being used, reducing setup times, reducing defects and rework, or increasing the skill level of the workers in the bottleneck station. It is also essential to consider the effect of any changes made on the production line, such as the cost benefits changes (Goldratt & Cox, 2016).

According to Table 8, the current production line had a cycle time of 20.25 seconds, resulting in a line efficiency of 46.21%. The first proposed method im-

Table 6
Excel simulation result of the first proposed method

Job	A	BD1	C	BD2	EF1	EF2	GHJ1	GHJ2	I	K
Number of workers	1	1	–	1	1	1	1	1	–	1
Number of machines	–	–	2	–	–	–	–	–	1	–
Average time in queue (min)	61.51	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Utilization of worker/machine	1.00	0.38	0.58	0.35	0.47	0.47	0.70	0.70	0.15	0.56
Average service time in system (sec)	12.86	5.20	15.00	4.47	5.74	6.35	18.28	18.18	2.00	7.22

Table 7
Excel simulation result of the second proposed method

Job	A	B	C	D	EF1	EF2	GHJ1	GHJ2	I	K
Number of workers	2	1	–	1	1	1	1	1		1
Number of machines	–	–	2	–	–	–	–	–	1	–
Avg. time in queue (min)	0.00	0.04	0.00	0.05	0.16	0.15	0.18	0.16	0.14	0.29
Utilization of worker/machine	0.85	0.69	0.99	0.60	0.76	0.84	0.89	0.90	0.38	0.72
Average service time in system (sec)	12.86	5.22	15.00	4.56	12.09	12.15	18.18	18.25	2.00	7.23

Table 8
Assessment of the present and suggested methods

Method	Performance Indicator	Current System	Proposed Method	
			1	2
Time Study and Simulation	Number of workers	10	8	9
	Number of reduced workers	–	2	1
	Number of stations	11	5	7
Time Study	Bottleneck cycle time (sec)	20.25	17.35	10.13
	Total cycle time per worker (sec)	74.78	58.21	56.50
	Line efficiency (%)	46.21	67.09	79.71
	Total time from time study (hr)	7.89	6.76	3.95
Simulation	Total simulation time (hr)	7.91	5.04	3.95
	Average queue time (mins)	13.49	5.72	0.10
	Average utilization of worker/machine	0.55	0.56	0.77
	Overtime cost (US$/month)	565.2	–	–
	Number of days to fulfil monthly demand without overtime production	15.80	10.21	7.90

proved the line efficiency to 67.09% by reducing the cycle time to 17.35 seconds. The second proposed method had the best results: a cycle time of 10.13 seconds and a line efficiency of 79.71%. In addition, the second proposed method also reduced the total production time significantly. This is because it focused on reducing the bottleneck cycle time in the first proposed method, which happened in job A. By allocating one more worker to this station and separating jobs B and D to be done by different workers, the waiting time was reduced, resulting in a faster production rate. The reduction in bottleneck cycle time and the increase in worker utilization led to a more efficient production line, with a higher output rate and lower production time. The second method proved to be an effective improvement over the current production line and the first proposed method, making it a better solution for the chilled beef production line. The second method also had a cycle time that was shorter than the takt time, meaning no overtime would be required and associated costs for the abattoir. Therefore, the second proposed method improved the production line most effectively. This outcome is comparable to that of Gundogar et al. (2016), who conducted a simulation in a production line for making furniture. In their study, the bottleneck was removed using a simulation-based heuristic method based on the Theory of Constraints (TOC) concept to balance the flow, which led to an average 88% increase in production.

The number of workstations in a production facility can significantly affect how resources are utilized and the company's overall expenses (Salazar, 2020). Utilization of resources, such as physical space and workforce, is essential for maximizing productivity. An idle workstation can lead to losses in productivity. While implementing improvements to the production line, it is necessary to consider the long-term effects and make adjustments to ensure workers' convenience. A simulation can be used to design an efficient production line, improve productivity, and reduce costs (Pisuchpen & Ongkunaruk, 2016). The simulation results for the current and second methods were similar to average time calculations. However, the first method in the simulation model had a total reduction in time of approximately 25.44%, which differed from the other methods. This discrepancy could lead to an incorrect decision when choosing the most effective improvement method. The time study used standard time, which accounts for allowances and rating factors that may result in an overestimation of the cycle time compared to the simulation method. Additionally, the difference in results may be due to errors or inconsistencies in the averages (Savage et al., 2012). The simulation generates scenarios that consider all possible real-world contingencies, making it a more comprehensive and reliable method for evaluating production line improvements. In this case, the second method was the most effective, potentially saving US$ 565.2 per month in overtime costs. Implementing this method would allow the abattoir to reduce costs and increase efficiency. Simulation can be more reliable than calculating the standard time for evaluating and improving production lines.

Conclusions

This research proposed a novel approach for improving the efficiency of a chilled beef production line by combining the theory of constraints, line balancing, and ECRS methods. The main achievement of this research is the development of a simulation model that was used to evaluate the production line and identify areas for improvement. The contribution of this research is the use of a simulation model in addition to the traditional work study method to evaluate the efficiency of the production line. By using this approach, the research can consider multiple scenarios based on random cycle times and account for potential errors in averages. The findings of this research revealed that by consolidating certain jobs and reallocating workers, the bottleneck cycle time was reduced, leading to a more efficient production line. In summary, this research demonstrated the effectiveness of using a simulation-based approach in combination with the Theory of Constraints, line balancing, and ECRS to improve the efficiency of a chilled beef production line. The simulation results were found to be more reliable than traditional time study methods, and the use of Microsoft Excel and Macros made the approach easy to apply without the need for specialized software. These techniques can be applied to other industries to improve their production line efficiency as well. However, if expertise in simulation is not available, traditional time study methods can still provide decision-makers with accurate information. The direction of further research would be a modification of the model to include specific information about the production line, such as the number of workstations, layout, workforce, and cycle time for each workstation in related industries. The allowance and the rating factor may differ due to the workers' varying labor rates. However, for contexts with significant levels of manual work, the optimization procedure would continue to be comparable to the one described in this study.

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