Work Cell Design to Improve Productivity in Cricket Husbandry

[1]Chanchai Laoha*, [2]Naphatara Intanon

[1][2]Department of Industrial Technology, Faculty of Technical Education,
Rajamangala University of Technology Isan Khonkaen Campus, 40000, Thailand.
*Corresponding author E-mail address: chanchai.la@rmuti.ac.th

Abstract

This study article explores the importance of improving the work cell architecture in a cricket house with the aim of enhancing productivity through the reduction of lean waste in operations. The use of work cell layout design optimization is considered the most appropriate strategy. This research incorporates several elements, including scheduling and sequencing, machine placement along the XYZ axes, the presence of restricted areas inside the factory, and the implementation of a flexible production process. This study encompasses three distinct work cell units, namely Unit 1, Unit 2, and Unit 3, in order to ascertain its efficacy. The idea of productivity is of utmost importance in the context of implementing ways to enhance productivity in terms of mean lifetime (in seconds), restricted space in a factory (square meters: m^2), operating time (minutes: min), and average traveled distance (meters: m). The utilization of simulation tools in modeling and analyzing work cell performance under different scenarios has been a common practice in the field of plant simulation programming, particularly via the implementation of Tecnomatix plant simulation programming. The academic contributions presented not only enhance the theoretical comprehension of work cells but also provide valuable counsel for enterprises seeking to adopt work cells by effectively connecting theoretical concepts with practical application.

Keywords: Cricket husbandry, Productivities, Simulation model, Work cell manufacturing.

1. Introduction

Cellular manufacturing is considered the fundamental principle of lean manufacturing, since it incorporates the integration of flow operations to enhance productivity and efficiency (Sanjaykumar, Zala, Gohil & Dave, 2023). The operational dynamics of cellular manufacturing, also known as a work cell, encompass a harmonious integration of human expertise, procedural protocols, machinery, and essential resources, ensuring a seamless progression from one stage of production to the next. However, if the synchronization of these components occurs without the simultaneous synchronization of other parts, it may result in a disruption of the workflow, ultimately leading to faults in the production line (Sharma & Nimawat, 2023). The ultimate result of this situation is the extension of lead times and the escalation of production prices. Numerous researchers are now focused on investigating constituents that have the potential to augment the robustness and effectiveness of cellular operations (YounesSinaki, Sadeghi, Mosadegh, Almasarwah, & Suer, 2023). The accuracy rate of each approach changes depending on the context and datasets employed (Sharma & Nimawat, 2023). The implementation of work cells is supported by many essential components that contribute to their greater adaptability and durability. These components include worker multiskills, one-piece flow, layout flexibility, and equipment (Renna, Materi & Ambrico, 2023; Ghaseminejad, Kazemipoor, & Fallah, 2023).

The presence of numerous machines, activities, and equipment in industrial settings poses challenges to the frequency and timing of tasks (Zhu, Jiang & Xiao, 2023). The scheduling and sequencing of work cells are strategically devised to optimize throughput, minimize setup durations, and reduce work-in-progress inventory (Wu et al., 2023; Gan, Musa & Yap, 2023). As a result, in order to tackle this problem and enhance the efficiency of finding solutions, researchers have suggested various approaches, such as the genetic algorithm (Renna et al., 2023). The real-world application of mathematical models for dynamic reconfiguration of layout and equipment adaptability is hindered by computational difficulties. A multitude of research papers have put forward complete remedies. The execution of repetitive activities within industrial processes is a considerable challenge due to the fluctuating human performance resulting from physical exhaustion and the issue of workers possessing multiple talents (Hu & Chen, 2017; Xiong, Tang, Kim & Rosen, 2023). The collaboration between humans and machines in the context of additive manufacturing serves to expand the capabilities of both parties involved. The optimization of layout design involves the creation of work cell layouts that aim to decrease travel lengths, alleviate bottlenecks, and improve the overall workflow (Zakirah, T., Emeraldi, R., Handi, O. M., Danil, D., & Kasih, T. P., 2018). All of these factors are taken into account while addressing various constraints, including geographical limits and the strategic positioning of equipment. According to Attia, Sobhi, Alarjani, and Karam (2023), as well as Pérez-Gosende, Mula, and Díaz-Madroñero (2023), the concept of dynamic workcell reconfiguration is relevant in situations when there are shifts in product demand, occurrences of machine failures, or other disturbances (Ravalji, Raval, Qureshi & Shukla, 2023). The primary goal is to reduce the amount of time that production is halted and to provide a continuous and uninterrupted flow of production activities (Davim, 2018). In order to maintain competitiveness in the dynamic industrial environment, manufacturers must effectively solve the identified flaws while capitalizing on the inherent benefits of work cell methodology. Therefore, within the context of lean manufacturing, the implementation of work cells in cell manufacturing aims to address issues related to labor scarcity, subpar productivity, and inadequate occupational health. This is achieved through the integration of production processes with labor resources, as highlighted in the studies conducted by Jamwal, Agrawal, Sharma, Dangayach, and Gupta (2023) and Ravalji, Raval, Qureshi, and Shukla (2023). Previous research has examined the effects of work cells on lean manufacturing. There exists a dearth of scholarly investigations pertaining to the impact of work cells on the enhancement of productivity. In such circumstances, it is advisable to employ the notion of work cell layout design as a means of enhancing productivity through the reduction of lean waste in operational processes. This research paper examines the fundamental elements of work cell layout design optimization, with a specific emphasis on human- machine interaction, scheduling and sequencing, machine placement along the XYZ axes, restricted area factories, and the implementation of a flexible production process. The study also incorporates the use of simulation for the purpose of analyzing productivity (Katsigiannis, Pantelidakis, & Mykoniatis, 2023). The good outcomes seen may be attributed to the potential influence of enhanced layout design methodologies.

2. Materials and methods

2.1 Data for simulation program

Crickets, along with several other insect species, have emerged as noteworthy economic insects and potential sources of alternative proteins. These insects are being endorsed by the Food and Agriculture Organization of the United Nations (FAO) as a means to produce cash for countries and their agricultural communities. According to Statista (2022), it is anticipated that the market value of insects in the United States of America (USA) will experience significant growth, reaching an estimated worth of 17.6 billion US dollars by the year 2032. According to UNCATEGORIZED (2022), Thailand is home to over 20,000 registered insect farming firms. The cricket home functions as a crucial environment for the well- being and development of crickets. This study article explores the relevance of optimizing the work cell arrangement in a cricket home, with a focus on decreasing distances, ensuring the functionality of the automatic water and food system, and building efficient linkages between workstations.

Figure 1 Layout of Cricket House

A cricket house normally consists of two rows containing six cricket boxes, as seen in Figure 1. A diligent employee is tasked with the regular upkeep of the automated water and feeding system in the cricket enclosures, ensuring that the nutritional requirements of the crickets are swiftly fulfilled on a bi-daily basis. On average, the yield of cricket husbandry in boxes is 12 kg per box. Currently, the functioning of cricket houses is predominantly dependent on physical labor. In order to prevent any instances of negligence, it is imperative that workers are granted unrestricted access to all boxes or workstations. Neglecting to do this maintenance task may result in the buildup of inventories.

2.2 Research Instrument

A work cell may be defined as a cohesive unit, including a collection of machinery and employees that collaborate to execute a well-defined and specialized activity. According to Uzunosmanoglu, Limère, and Raa (2023), the implementation of a well-optimized work cell has the potential to enhance process efficiency, minimize error occurrences, and achieve cost reduction. The creation of an effective and productive work environment in work cell design and layout necessitates the careful consideration of several components and factors (Pérez-Gosende, Mula & Díaz-Madroñero, 2023). The objective of these aspects is to enhance the optimization of scheduling and sequencing, machine placement along the XYZ axes, constrained area factories, and flexible production processes within the cell. The research encompasses three distinct work cell units, namely Unit 1 (comprising work cells 1-4), Unit 2 (comprising work cells 5-8), and Unit 3 (comprising work cells 9-12). Primarily, it is imperative that the system be capable of being adjusted to meet the transition from a manual to a flexible manufacturing process, all the while ensuring the well-being and protection of the crickets. In Thailand, there is a growing utilization of work cell production in the field of cricket husbandry, which presents a distinctive use.

2.3 Collection of data

This study article compiles data pertaining to work cell manufacturing, mean lifetime (in seconds), cricket husbandry area (in square meters), operating duration (in minutes), and average traveled distance. The data is collected within the framework of sustainable cricket farming in Thailand.

2.4 Analysis of data

2.4.1 Key performance on box for cricket husbandry with automation

The productivity concept plays a significant role in ensuring the success of sustainable cricket farming. It encompasses many measurements aimed at boosting productivity, such as mean lifetime (sec), cricket husbandry area (m^2), operating time (min), and average traveled distance (m). The formula below outlines the relationship between these factors.

Formula: Productivity = [Output/Input] [1]

The utilization of simulation tools, such as Tecnomatix plant simulation, is frequently employed in the modeling process. This technique offers a novel means of examining the performance of work cells across different scenarios (Ďuriška, Fedorko, Fabianová, Molnár, Neradilová & Dolák, 2023; Bendowska & Zawadzki, 2023). According to Zhu (2023), this approach enables the conduct of testing and optimization processes without causing any disruptions to real production operations.

2.4.2 Worker operation on box for cricket husbandry with automation

The acquisition of input data for cricket husbandry is of utmost importance in order to guarantee the importation of precise data into the simulation. Therefore, it is important to collect the primary dataset and evaluate the appropriateness of probability distribution functions for the input data within the Arena simulation software, as stated by Attia et al. (2023).

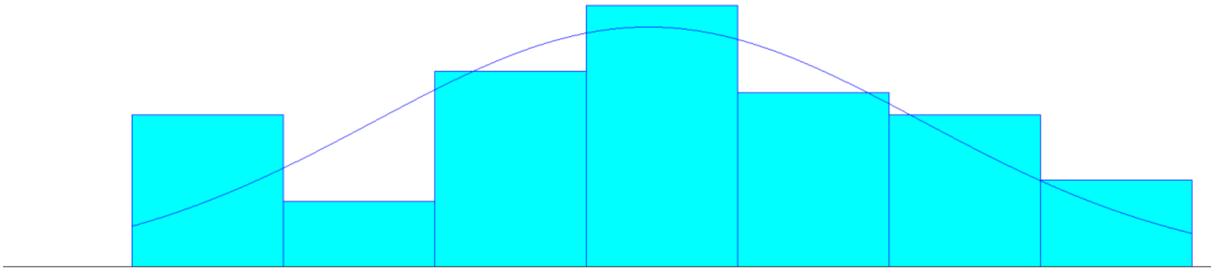

Figure 2 Fit of probability distribution functions to input data by arena simulation program.

Figure 2 illustrates the process of fitting probability distribution functions to the input data using the arena simulation. The dataset consists of worker operations on box A over a specific period of time in the context of cricket husbandry, utilizing automation. The sample size for this dataset is 50. The probability distribution has a normal distribution, characterized by a sample mean of 4.46, a standard deviation of 0.783, a minimum value of 3.04, and a maximum value of 5.98.

2.4.3 Data input of cricket husbandry with automation on plant simulation

In the process of modeling within a simulation program, there are two essential steps:

1) Creating a prototype model that can be further customized to accommodate various scenarios.

2) Fine-tuning the prototype model to align with the desired scenario.

The process of modeling entails the establishment of an entity as a fundamental constituent of the model. This study has identified four primary toolsets in the field of plant simulation, namely, material flow, sources, information flow, and user interface. The toolboxes mentioned in Table 1 play a crucial role in the simulation process.

Table1 Cricket husbandry operation in simulation model

Toolbox		**Cricket husbandry operation**
Material Flow		
	Station	Box for cricket husbandry with automation
	Source	Entity for call Woker from work pool working to make ensures the system is inspected twice daily to guarantee the crickets' nutritional needs are met promptly
	Drain	Entity out from simulation system
Sources		
	Woker pool	Release worker working
	Broker	Make the quantity of worker
	Worker place	Worker place

Toolbox	Simulation Parameter	Initial Layout and all Scenarios
Information Flow		
	Method	Retrieve data to display in Variable
	Variable	Variable in cricket husbandry operation
	Method	Formula for variable
	Data Table	Create the Time of creation on Source object chose
User Interface		
	Sankey Diagram	Create worker root

Subsequently , the simulation parameters are being adjusted inside the toolbox to accurately depict the cricket husbandry activity, as seen in Table 2.

Table2 Object setting on Simulation program on Cricket husbandry operation

Toolbox	Simulation Parameter	Initial Layout and all Scenarios
Source	Time of creation on Source object chose Delivery Table	Delivery Table put 2 Time/day on morning time and afternoon time
Station	Processing Time on station object chose formula	z_normal(procTimes[1,@.name],procTimes[2,@.name], procTimes[3,@.name],procTimes[4,@.name],procTimes[5,@.name])
Station	Importer tap on station object	Chose active
Station	Service on processing of importer tab	Put processing
Workplace	Support service on Attributes tap	Put processing
Method		OperationalTime:=.Resources.Worker:20.StatExporterOperationalTime EnRouteToJobTime:=.Resources.Worker:20.StatServicesEnRouteToJobTime WorkingTime:=.Resources.Worker:20.StatServicesWorkingTime
M=1	Data type on value tab	Click time

The consideration of delivery time encompasses scheduling and sequencing, among other aspects. The data table containing the source toolbox in the simulation model was populated with information twice a day, during both morning and afternoon periods, as seen in Table 3.

Table3 Delivery Table put 2 Time/day on morning time and afternoon time.

String	Delivery Time	MU	Q'TY	Box number
1	6:00:00.0000	.MUs.Part	1	B1
2	11:00:00.0000	.MUs.Part	1	B1
3	6:10:00.0000	.MUs.Part	1	B2
4	11:10:00.0000	.MUs.Part	1	B2
5	6:20:00.0000	.MUs.Part	1	B3
6	11:20:00.0000	.MUs.Part	1	B3
7	6:30:00.0000	.MUs.Part	1	B4
8	11:30:00.0000	.MUs.Part	1	B4
9	6:40:00.0000	.MUs.Part	1	B5

10	11:40:00.0000	.MUs.Part	1	B5
11	6:50:00.0000	.MUs.Part	1	B6
12	11:50:00.0000	.MUs.Part	1	B6
13	7:00:00.0000	.MUs.Part	1	B7
14	12:00:00.0000	.MUs.Part	1	B7
15	7:10:00.0000	.MUs.Part	1	B8
16	12:10:00.0000	.MUs.Part	1	B8
17	7:20:00.0000	.MUs.Part	1	B9
18	12:20:00.0000	.MUs.Part	1	B9
19	7:30:00.0000	.MUs.Part	1	B10
20	12:30:00.0000	.MUs.Part	1	B10
21	7:40:00.0000	.MUs.Part	1	B11
22	12:40:00.0000	.MUs.Part	1	B11
23	7:50:00.0000	.MUs.Part	1	B12
24	12:50:00.0000	.MUs.Part	1	B12

The processing time for the station object was determined using a chosen formula and afterwards recorded in the data table of the station toolbox within the simulation model, as seen in Table 4.

Table4 Parameter to formula in Processing Time on station object

String	name	steam	MU	Sigma	lower	upper
1	A	1	4.46	0.78	3.04	5.98

The researchers proceeded to construct the prototype model in accordance with the specified starting architecture and scenarios 1-4, as seen in Figure 3-7 of the Tecnomatix plant simulation program. The machine location was evaluated based on the XYZ axes, the restricted area inside the factory, the process flow, and the flexibility of the manufacturing process.

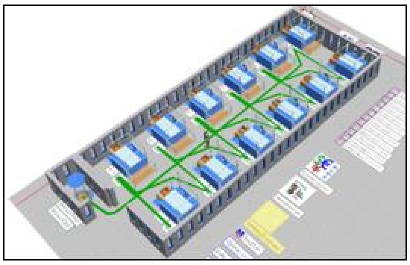

Figure 3 Initial work cell

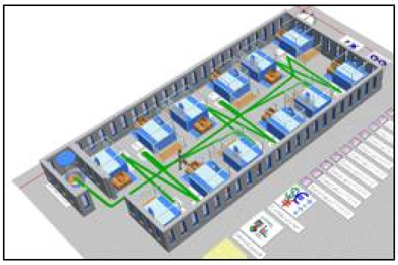

Figure 4 work cell in Scenario 1

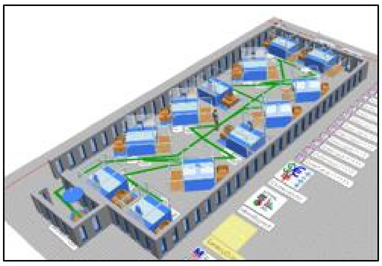

Figure 5 work cell in Scenario 2

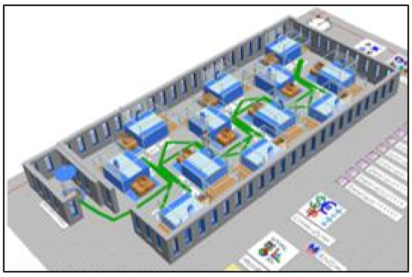

Figure 6 work cell in Scenario 3

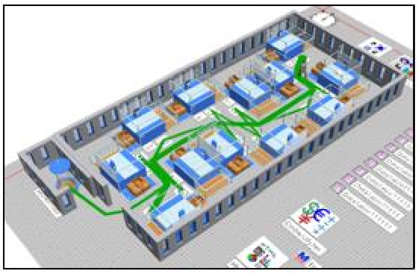

Figure 7 work cell in Scenario 4

The Sankey diagram symbolizes the generation of workers, who serve as the foundation for the modeling of movement inside work cells in the context of cricket husbandry house placement.

3. Results

An essential component of cricket husbandry is comprehending the allocation of worker effort towards the upkeep of water and food provision within a confined space, as represented by the average lifespan in simulation modeling. Table 5 examines the impact of worker operation on the estimation of mean lifetime based on work cell architecture, scheduling, and sequencing. This study employs a scenario analysis to demonstrate the relevance of its use inside the work cell of cricket farming. In such situations, it is advisable to employ the notion of layout design optimization as a means to mitigate lean waste in operational processes.

Table5 Mean lifetime

Box number of cricket husbandry	**Mean Lifetime (Sec)**				
	Initial work Cell in Scenario	**Work Cell in Scenario 1**	**Work Cell in Scenario 2**	**Work Cell in Scenario 3**	**Work Cell in Scenario 4**
Average	10.00	9.74	8.56	8.75	8.41
Standard Deviation	3.43	2.68	3.57	4.35	3.66
Productivity	[(12kg ● 3.35$)/10] = 4.02 $/Sec	[(12kg ● 3.35$)/9.74] = 4.12 $/min	[(12kg ● 3.35$)/8.56] = 4.69 $/min	[(12kg ● 3.35$)/8.75] = 4.59 $/min	[(12kg ● 3.35$)/8.41] = 4.78 $/min

In the fourth scenario, the work cell exhibits a mean processing time of 8. 41 seconds, accompanied by a standard deviation of 3.66. The given example demonstrates that the work cell with a mean lifespan of 4. 78 seconds achieves the highest production.

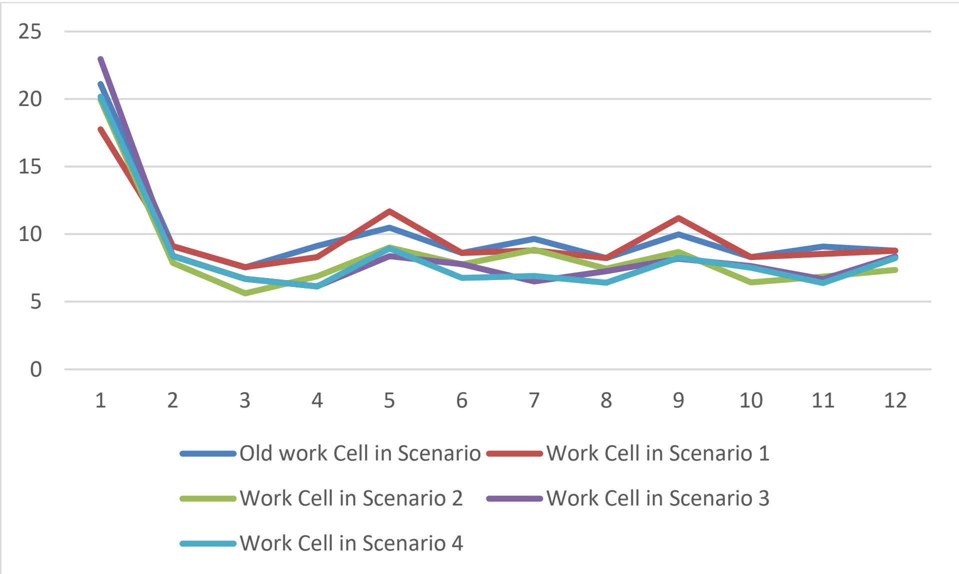

Figure 8 Mean lifetime trend

Figure 8 illustrates the trend of the mean lifespan. Upon analyzing the plot graph illustrating the trend of mean longevity, a coherent pattern becomes evident. The mean lifetime of Cricket Box 1 consistently demonstrates the greatest value across all scenarios. Additionally, there is an observable rising tendency in the data for boxes 5 and 9.

Table6 Cricket husbandry output

Output	Initial work Cell in Scenario	Work Cell in Scenario 1	Work Cell in Scenario 2	Work Cell in Scenario 3	Work Cell in Scenario 4
Cricket husbandry area (m^2)	(10x24) 240	(10x20) 200	(10X23) 230	(10x20) 200	(10x20) 200
Productivity	[(12kg ● 3.35$)/240] =0.167 $/$m^2$	[(12kg ● 3.35$)/200] = 0.201 $/$m^2$	[(12kg ● 3.35$)/230] = 0.174 $/$m^2$	[(12kg ● 3.35$)/200] = 0.201 $/$m^2$	[(12kg ● 3.35$)/200] = 0.201 $/$m^2$
Operational Time (Minutes)	3:59	3:52	3:24	3:28	3:20
Productivity	[(12kg ● 3.35$)/ 3.59 Minutes] = 242.21 $/min	[(12kg ● 3.35$)/ 3:52 Minutes] = 249.52 $/min	[(12kg ● 3.35$)/ 3:24 Minutes] = 283.76 $/min	[(12kg ● 3.35$)/ 3:28 Minutes] = 278.31 $/min	[(12kg ● 3.35$)/ 3:20 Minutes] = 289.44 $/min
Average traveled distance	201	192	149	156	144
Productivity	[(12kg ● 3.35$)/201] = 0.200 $/m	[(12kg ● 3.35$)/192] = 0.209 $/m	[(12kg ● 3.35$)/149] = 0.269 $/m	[(12kg ● 3.35$)/156] = 0.257 $/m	[(12kg ● 3.35$)/144] = 0.279 $/m

The dimensions of the cricket husbandry area in square meters, the operational time in dollars per minute, and the average journey distance all have significant impacts in these situations. The work cells in scenarios 1, 3, and 4 necessitate a reduced cricket husbandry space. In situations 4, there is a correlation between work cells and reduced operation time. Significantly, the differentiation lies in the attainment of the smallest average distance traveled. The optimization of productivity is a significant focal point across many sectors. In the domain of cricket husbandry, the enhancement of output necessitates a meticulous analysis of labor cells. The work cell in scenarios 1, 3, and 4 exhibits high production in the cricket husbandry domain, with a cost of 0.201 $/m2. The work cell in scenario 4 has a high level of productivity in terms of operation time, with a rate of 289.44 $/min. The work cell in scenario 4 has high productivity in terms of average traveled distance, with a cost of 0.279 dollars per meter.

4. Discussion

The objective of this study is to optimize the efficiency of cricket husbandry in an automated enclosure by reducing resource waste. The researchers discovered that scenario 4 demonstrates superior production in automated box farming, as evaluated by the area covered. Zakirah et al. (2018) assert that optimizing the warehouse layout for staff workflow leads to enhanced space utilization. According to Rajeh (2023), the allocation of bottlenecks among workstations at a facility is influenced by the availability of workers and equipment, particularly in relation to the size of the facility. In a study conducted by Hovanec, Korba, Vencel, and Al-Rabeei (2023), it was shown that many parameters, such as the size of the workspace, the position of the production line, and the logistical placement, had a significant influence on production time and overall productivity. These factors were seen to contribute to a decrease in production time and an improvement in efficiency. Scenario 4 demonstrates increased productivity in the operational period of work cell production, specifically in the context of cricket husbandry. Attia et al. (2023) provide evidence supporting the proposition that the incorporation of human mobility inside workstations may effectively boost productivity through the elimination of waste, the implementation of one-piece flow, cellular manufacturing, and the integration of resources. In their recent study, Gao, Feng, Zhang, Wang, and

Yang (2023) put out a proposal for an optimal layout plan. This plan aims to enhance the daily production of head lettuce within the specified objective while also improving overall productivity when compared to the initial layout plan. The average distance traveled for work-related purposes in the context of rising cricket husbandry as a kind of cell manufacturing is positively correlated with greater levels of productivity. Sadar et al. (2023) emphasize the significance of digital manufacturing in mitigating geographical barriers, optimizing workforce organization, and augmenting the efficacy of current product lifecycle arrangements.

The utilization of Tecnomatix plant simulation is employed to accurately depict the authentic manufacturing process involved in the creation of printed components through the utilization of multi-jet fusion printers, encompassing the consideration of trip distance. Scenario 4 demonstrates a greater level of production in the agricultural sector through the utilization of automated box technology during the course of its operational lifespan. The good outcomes seen may be attributed to the potential influence of enhanced layout design methodologies. These approaches encompass the consideration of scheduling and sequencing, machine placement, restricted area factories, and flexible production processes that involve the grouping of machines for enhanced operational flexibility. The allocation of machines to certain cells in product routings is determined by their positioning along the XYZ axes. The adoption of effective layout design techniques leads to a decrease in waste generated by excessive transit and waiting time for automated cricket boxes, which in turn requires employees to supervise the automation process, resulting in a reduction in the average lifespan of the equipment. The findings indicate that the implementation of a work cell layout has the potential to enhance anticipated productivity levels and mitigate the presence of lean waste. Uzunosmanoglu, Limère, and Raa (2023) put forth the proposition of achieving cost reduction through the optimization of resource allocation, transportation, and processing.

These contributions not only enhance the theoretical comprehension of work cells but also provide practical direction to enterprises seeking to adopt work cells by effectively connecting theory with real-world application. The adaptability of this approach allows for the management of production capacity variations resulting from changes in demand as well as the incorporation of technological advancements in manufacturing systems to handle goods with shorter life cycles. This study aims to inspire academics and practitioners to devise targeted and efficient solutions by using their understanding of cellular manufacturing.

Academic experts play a vital role in advancing the field of teaching Tecnomatix plant simulation programs, namely in the areas of work cell design and lean manufacturing. Their contributions are crucial in facilitating the education and preparation of future manufacturing professionals. Hariom, Kailash, Krapal, and Dharamender (2023) have put up a paradigm that aims to enhance manufacturing frameworks, resulting in favorable practical outcomes and management insights. In a recent study conducted by Banu, Padhi, Shukla, Ramakrisnan, and Thandayuthapani (2023), the significance of training and development in maintaining the long-term viability of organizations was underscored. The researchers also stressed the favorable effects of investing in employees on productivity, specifically through the implementation of work cell flexibility.

Finding: The research study highlights the importance of prioritizing open space in the workstation unit. The research centers its attention on three distinct work cell units, namely Unit 1, Unit 2, and Unit 3. The issues associated with organizing work cell units in a residential setting are identified. The interconnections between units, specifically boxes 4 to 5 and 8 to 9, have the highest average lifespan. The challenge at hand pertains to the architecture of the work cell unit, taking into account many factors such as production schedule, working pathways, limits imposed by the business house, size of the machine area, and workflow. This also involves the grouping of flexible machines depending on their position along the XYZ axes in product routings or other relevant criteria. In the context of future work cell manufacturing implementation, it is important to take into account the factors of overall equipment effectiveness (OEE) and the challenges associated with automated production by robots.

5. Conclusions

This study article explores the importance of improving the work cell architecture in a cricket house with the aim of enhancing productivity through the reduction of lean waste in operations. The use of the idea of work cell layout design optimization is deemed to be the most appropriate technique. The cricket house comprises two rows, with each row accommodating six cricket boxes that function as essential habitats for the well-being and development of the crickets. The diligent employee is tasked with the responsibility of ensuring the proper functioning and upkeep of the automated water and feeding system within the enclosures housing the crickets. This research incorporates several elements, including scheduling and sequencing, machine placement along the XYZ axes, a constrained area inside the factory, and the implementation of a flexible production process. This study encompasses three distinct work cell units, namely Unit 1, Unit 2, and Unit 3, in order to ascertain its efficacy. The idea of productivity holds significant importance in the realm of sustainable cricket farming, particularly in relation to measures aimed at boosting productivity in terms of mean lifetime (Sec), cricket husbandry area (m^2), operating time (minutes), and average traveled distance (m.). The use of simulation tools inside the Tecnomatix plant simulation programming has frequently encompassed the application of simulation tools to depict and evaluate the performance of work cells across different situations. The findings indicate that work cell scenarios 1, 3, and 4 exhibit great production in the cricket husbandry field, with a cost of 0.201 $/m2. The work cell in scenario 4 has a high level of productivity in terms of operating time, with a value of 289.44 $/min. The work cell in scenario 4 has high productivity in terms of average traveled distance, with a cost of 0.279 dollars per meter.

6. Acknowledgements

This research project is supported by Thailand Science Research and Innovation (TSRI). Contract No. FF66-P1-133.

References

[1] Sanjaykumar, H., Zala, A. V., Gohil, K.G. & Dave, V .B. (2023). Patel. Review Paper on Lean Six Sigma Methodology for automotive Industries. Journal of Harbin Engineering University, 44(8), 602 – 610

[2] Sharma, V. & Nimawat, D. (2023). Cellular manufacturing system: a descriptive bibliometric analysis, framework, implementation steps and future research direction. Benchmarking: An International Journal, https://doi.org/10.1108/BIJ-11-2021-0703

[3] YounesSinaki, R., Sadeghi, A., Mosadegh, H., Almasarwah, N., & Suer, G. (2023). Cellular manufacturing design 1996–2021: A review and introduction to applications of Industry 4.0. International Journal of Production Research, 61(16), 5585-5636.

[4] Ladiya, L., & Yadav, T. K. (2023). Implementation of Lean Manufacturing Tools in Manufacturing Industries. International Journal of Science Management & Engineering Research (IJSMER) 07(03), 1092-1098

[5] Zhu, X., Jiang, L., & Xiao, Y. (2023). Study on the optimization of the material distribution path in an electronic assembly manufacturing company workshop based on a genetic algorithm considering carbon emissions. Processes, 11(5), https://doi.org/10.3390/pr11051500

[6] Renna, P., Materi, S., & Ambrico, M. (2023). Review of Responsiveness and Sustainable Concepts in Cellular Manufacturing Systems. Applied Sciences, 13(2), https://doi.org/10.3390/app13021125

[7] Ghaseminejad, A., Kazemipoor, H., & Fallah, M. (2023). Modeling the robust facility layout problem for unequal space considering health and environmental safety criteria under uncertain parameters. Decision Making: Applications in Management and Engineering, 6(2), 426-460.

[8] Xiong, Y., Tang, Y., Kim, S., & Rosen, D. W. (2023). Human-machine collaborative additive manufacturing. Journal of Manufacturing Systems, 66, 82-91.

[9] Hu, B., & Chen, J. (2017). Optimal task allocation for human–machine collaborative manufacturing systems. IEEE Robotics and Automation Letters, 2(4), 1933-1940.

[10] Zakirah, T., Emeraldi, R., Handi, O. M., Danil, D., & Kasih, T. P. (2018). Warehouse layout and

workflow designing at PT. PMS using systematic layout planning method. In IOP Conference Series: Earth and Environmental Science. 195(1), 1-8. DOI 10.1088/1755-1315/195/1/012026
[11] Attia, E. A., Sobhi, N., Alarjani, A., & Karam, A. (2023). Improving electric motor assemble using one piece flow, ergonomics, and cellular layout. International Journal of Simulation Modelling (IJSIMM), 22(2). 255-266
[12] Wu, Z., Zong, F., Zhang, F., Wang, J., Zhu, Z., Guo, X., & Cao, P. (2023). Investigation of the customized furniture industry's production management systems. Journal of Engineering Research, (Article in press) https://doi.org/10.1016/j.jer.2023.100072.
[13] Gan, Z. L., Musa, S. N., & Yap, H. J. (2023). A Review of the High-Mix, Low-Volume Manufacturing Industry. Applied Sciences, 13(3), 1-35 https://doi.org/10.3390/app13031687
[14] Ravalji, J. M., Raval, S. J., Qureshi, G., & Shukla, H. (2023). Insightful implementation of lean tools to cultivate lean culture in a small scale manufacturing organisation-a case study. International Journal of Industrial and Systems Engineering, 44(1), 52-74.
[15] Davim, J. P. (Ed.). (2018). Progress in lean manufacturing. Springer.
[16] Jamwal, A., Agrawal, R., Sharma, M., Dangayach, G. S., & Gupta, S. (2023). Lean manufacturing implementation challenges: a case study of pharmaceutical industries in Himachal Pradesh (India). International Journal of Business and Systems Research, 17(4), 462-481.
[17] Ravalji, J. M., Raval, S. J., Qureshi, G., & Shukla, H. (2023). Insightful implementation of lean tools to cultivate lean culture in a small scale manufacturing organisation-a case study. International Journal of Industrial and Systems Engineering, 44(1), 52-74.
[18] Katsigiannis, M., Pantelidakis, M. and Mykoniatis, K. (2023), "Assessing the transition from mass production to lean manufacturing using a hybrid simulation model of a LEGO® automotive assembly line", International Journal of Lean Six Sigma, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/IJLSS-07-2022-0165
[19] Statista.(2022). Forecast market value and volume of edible insects worldwide from 2032 to 2032. Retrieved from https://www.statista.com/statistics/882321/edible-insects-market-size-global/
[20] Uzunosmanoglu, M., Limère, V., & Raa, B. (2023). Design of Reconfigurable Cellular Manufacturing Systems with Alternative Routing. In IFIP International Conference on Advances in Production Management Systems (pp. 385-399). Cham: Springer Nature Switzerland.
[21] Pérez-Gosende, P., Mula, J., & Díaz-Madroñero, M. (2023). A bottom-up multi-objective optimisation approach to dynamic facility layout planning. International Journal of Production Research, 1-18.
[22] Ďuriška, M., Fedorko, G., Fabianová, J., Molnár, V., Neradilová, H., & Dolák, F. (2023). Use of a Software Application to Generate a Sequence for Simulation Model Creation. Applied Sciences, 13(9), 1-13.
[23] Bendowska, K., & Zawadzki, P. (2023). Development and Verification of a Simulation Model of an Automated Assembly Line. Applied Sciences, 13(18), 10142.
[24] Rajeh, H. (2023). Discrete Event Simulation of a Sawmill for productivity improvements : A simulated model for a sawmill to improve the production efficiency (Dissertation). Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-20572
[25] Hovanec, M., Korba, P., Vencel, M., & Al-Rabeei, S. (2023). Simulating a Digital Factory and Improving Production Efficiency by Using Virtual Reality Technology. Applied Sciences, 13(8), https://doi.org/10.3390/app13085118
[26] Gao, G., Feng, Y., Zhang, Z., Wang, S., & Yang, Z. (2023). Integrating SLP with simulation to design and evaluate facility layout for industrial head lettuce production. Annals of Operations Research, 321(1-2), 209-240.
[27] Sadar, M. P., Rajmore, K. G., Rodge, M. K., & Kumar, K. (2023). Digital manufacturing approach for process simulation and layout optimization. Materials Today: Proceedings, 74, 642-649.
[28] Hariom, Kailash, C. S., Krapal, S., & Dharamender, S., (2023) Inventory Modelfor Time-DependentLinear Demand with Three Levels of Production with Shortage. Journal of Harbin Engineering University, 44(8), 2025-2038.
[29] Banu, S. R., Padhi, A., Shukla T. D., Ramakrisnan H. & Thandayuthapani, S., (2023). Impact of Various types of Training Programs on OrganizationalSustainability, Journal of Harbin Engineering University, 44(7),621-627

[30] Pablo Pérez-Gosende, Josefa Mula & Manuel Díaz-Madroñero (2023) A bottom-up multi-objective optimisation approach to dynamic facility layout planning, International Journal of Production Research, DOI: 10.1080/00207543.2023.2168308

[31] UNCATEGORIZED. (2022). Insect farming in Thailand. Retrieved from https:// www.plantagbiosciences.org/peopl e/george-obrien/2022/08/31/insect-farming-in-thailand/