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ORIGINAL RESEARCH PAPER

LAYOUT DESIGN FOR FOOD SAFETY IMPROVEMENT OF FROZEN CRISPY CHICKEN CURRY PUFF PROCESSING

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Abstract

Cross movement between workstations, and inefficient material flow during the production process results in cross-contamination of food products. The purpose of this study is to develop a new layout design for a SME manufacturing frozen crispy chicken curry puff in Malaysia. Facility Sanitary Design Checklist was used in evaluating the establishment of hygiene zone, and workers and material flow. A new layout was developed using activity relationship analysis. The result revealed that hygiene zone establishment of the existing layout was 38.5%. The worker and material flows were poorly controlled with a score of 22.5%. The workstation arrangement in the new layout was developed in the true order of product flow based on closeness rating. The new layout scores higher marks in the application of hygiene zone (78.8%) and worker and material flow (90%) in most criteria compared to the existing layout. The new layout created new workstations and provided new facilities such as a separate change room, travel pathway, and access to high hygiene zone areas to avoid contamination risk and mix of worker traffic. Overall, new layout development produced an improved layout design in terms of workstation arrangement, hygiene zone segregation, and worker and material flow in solving SME layout problems.

Keywords: activity relationship analysis, cross-contamination, food safety, hygiene zone, layout design, worker and material flow

Introduction

Layout design has become a fundamental basis that can impact work efficiency in today's food processing plants (Vaidya *et al.*, 2013; Fitriani *et al.*, 2015). The design of the food plant is unique and it has been one of the most critical

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components in producing safe food products. The process requires consideration of internal and external factors that can affect the quality and safety of food products including sensitive components and shelf life of raw ingredients (Hasnan *et al*., 2014; Hasnan *et al*., 2019). A well designed layout in a food processing plant is able to control the flow of food materials and workers (Clark, 2008). It also could facilitate the movement of materials in the plant in a hygienic way by creating effective segregation of workstations that minimize the possibility of contamination of food with hazards (Maller, 2011; Lelieveld *et al*., 2014; Holah, 2014). In food safety, food hazards can be managed by the prerequisites programme and by Hazard Analysis Critical Control Point (HACCP) using generic hygienic food infrastructure and layout design, Good Manufacturing Practices (GMP), and Good Hygiene Practices (GHP). The design and layout of work areas should allow the implementation of good food hygiene practices and protection against contamination between and during operations (Lelieveld *et al*., 2014).

The Grocery Manufacturers Association (GMA) played a significant role in developing guidelines and checklists of equipment and facility design to self-evaluate compliance with sanitary design principles. A study by Hasnan *et al.* demonstrated the use of Principles 1 and 2 of the GMA scoring checklist tool in examining hygienic zoning and personnel and material flow of the existing plant layout and the spine layout design developed for a small-scale burger patties company. The existing layout scored less and a comparison of both designs had drawn attention to the issue that has been commonly neglected in the food industry today where food manufacturers failed to provide a proper design related to hygienic zoning and area segregation in plant layout (Hasnan *et al.*, 2019).

Activity Relationship Chart (ARC) under Systematic Layout Planning (SLP) procedures is one of the most common approaches in designing a new layout for food processing plants (Nanthasamroeng *et al*., 2012; Ojaghi *et al*., 2015; Banjarat *et al*., 2019; Dewi *et al*., 2020). The relationship of each department or workstation was analyzed using ARC and Total Close Rating (TCR) to determine the most critical adjacency between departments and the order in which departments should be selected in the algorithm (Ojaghi *et* al., 2015). Several layout studies have been conducted to reduce production length and circulation inside the plant and consequently boost production efficiency of food processing as the case studies especially involving Small Medium Enterprises (SMEs) industries. This has emerged as a good platform for addressing and solving issues related to layout design that are commonly faced by SMEs where they usually experienced poor layout planning and are not ready to invest in layout design that meets the requirements or standard due to lack of knowledge and scarce financial resources. This condition has led to an inefficient display of production facilities and workstations (Hasnan *et al.*, 2014).

Up to now, extensive research has been carried out in developing and improving the layout of the food processing plants (Amit *et al*., 2012*;* Nanthasamroeng *et al*., 2012; Hasnan *et al*., 2014; Ojaghi *et al*., 2015; Wanniarachchi *et al*., 2016; Banjarat *et al*., 2019; Hasnan *et al*., 2019; Putri and Dona, 2019; Dewi *et al*., 2020). Apart from that, a considerable amount of literature on food hygiene aspects is available in various disciplines (Young *et al*., 2019; Lee and Seo, 2020; Mirzay Razaz *et al.*, 2021). However, still, far too little attention has been paid to hygiene application on facility layout design and the impact on cross-contamination (Wanniarachchi *et al*., 2016; Acosta *et al*., 2021). Addressing this gap is crucial as cross-contamination risks associated with foodborne illness can be life-threatening. In fulfilling the gap, this study applied a multidisciplinary approach of layout design principles in production engineering and the food safety area to develop better layout design for the SME.

FFF Company is a food SME located in a food industrial complex with facilities that meet the GMP. The problem found in this plant layout is the arrangement of workstations in the production process. These sites had not been designed for specific food processing purposes of frozen crispy chicken curry puff (FCCCP) while taking into account food safety aspects, and hygienic zoning applications within the area. The production process creates unnecessary cross-movement between high and medium hygienic zone workstations. This condition affects the inefficient flow of materials and worker movement, besides increasing the contamination risk. Therefore, this study focuses on improving the layout design for a frozen crispy chicken curry puff processing company while considering the hygienic zoning, worker and materials flow, and closeness between workstations according to food safety and significance of each activity interrelationship.

Materials and methods

Background of the production process and original plant layout

The layout drawn along with the process flow of FCCCP is shown in Figure 1. Seven main facilities were involved in the production; storage, washing, cooking, mixing, production, blast freezer for rapid freezing process, and packaging. The storage facility consists of areas to store dry food ingredients, cold storage (freezer and chiller), packaging materials, and chemicals, while the administrative area is located outside the processing area and therefore not included in the layout.

Assessment of sanitary design of existing layout

The sanitary design of the existing layout was assessed using GMA scoring checklist tools. Two principles of the GMA tools; Principle 1 - to evaluate the hygiene zone application and Principle 2 – to evaluate worker and materials flow. Observation and inspections during site visits were applied to complete the checklist to assess the compliance of the plant with GMA sanitary design principles before being verified by staff responsible for quality assurance and control in FFF. The checklist was designed as a guideline to support ten principles of sanitary design for food processing establishments in identifying problems and potential design flaws related to operational sanitation concerns (CBA, 2020). The checklist tool has been recommended due to its effectiveness in carrying out at all project stages and facilitating the hygiene design review process (Nikoleiski, 2012; 2015).

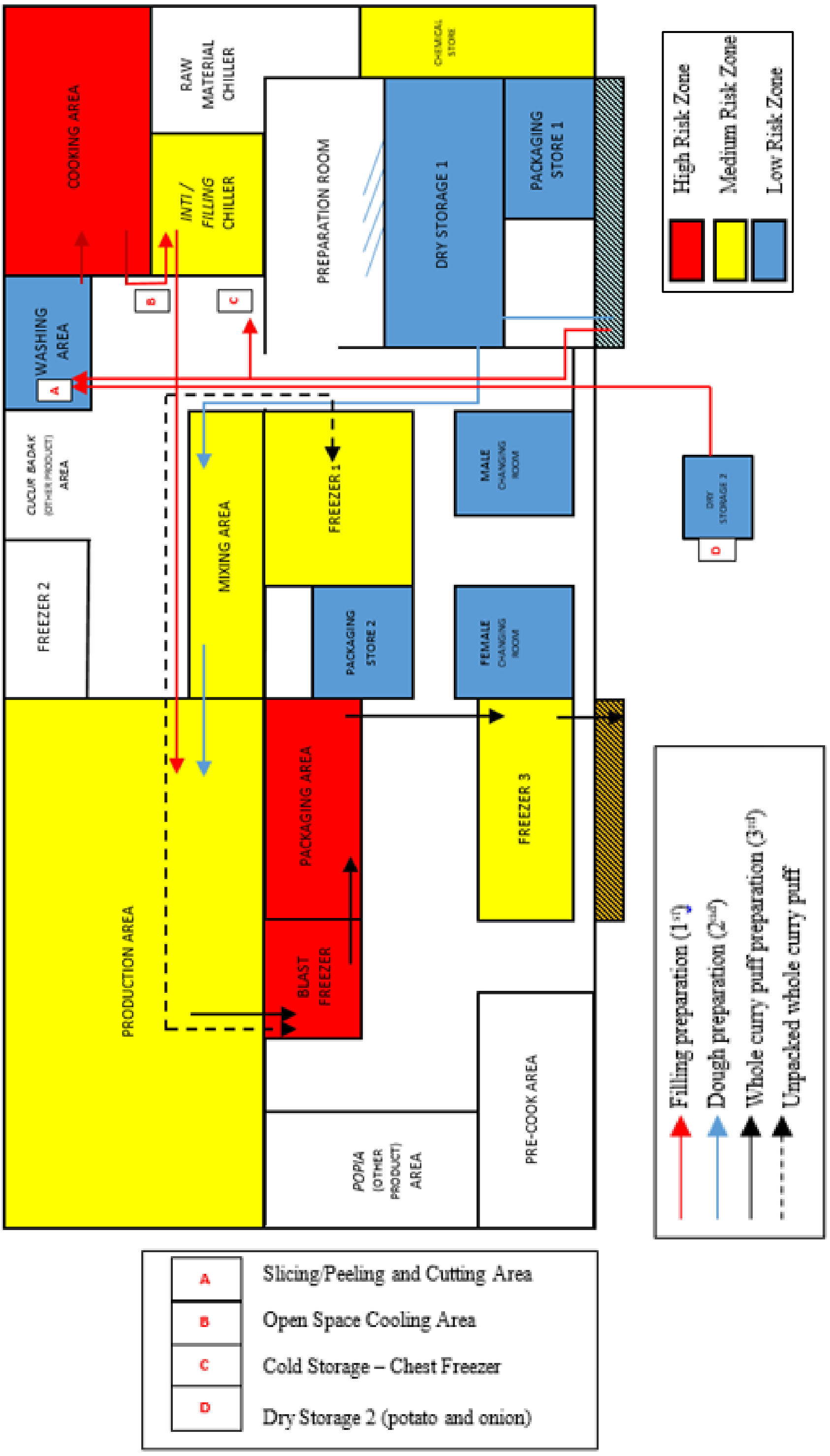

Figure 1. FFF existing layout of FCCCP processing.

Principle 1 covers six requirements, while Principle 2 comprises four requirements to be assessed and scored based on GMA criteria. The checklist scoring was based on four categories; (S) satisfactory where all available points are awarded, (M) marginal where half of the points are awarded, (U) unsatisfactory where no points are awarded, and (N) where the criteria are not applicable and available points are reset to zero. The checklist tool automatically calculates points based on the answers.

Activity relationship analysis

Sensitive and perishable raw materials in the food processing industry have led to the consideration of cross-contamination risk in analyzing the relationship between activities. Activity relationship analysis was one of the systematic layout planning procedures where workstations in processing plants will be arranged according to high-frequency movement and relationships close to each other (Barnwal and Dharmadhikari, 2016).

A total of 22 activities are involved in the frozen crispy chicken curry puff filling and skin production process. These activities were grouped into similar workstation areas and analyzed using the activity relationship indices; A, E, I, O, and U which represent absolute necessary, especially important, important, unimportant, and undesirable respectively. Heavy traffic of workers and auxiliary materials flow along with the production processes or between workstations was taken into account during the activity relationship analysis (Hasnan *et al*., 2019). Adjacency between each workstation was arranged based on the closeness of activity relationship and total closeness rating (TCR), where they were adjacency located on the same or opposite side. The process was continued until all workstations were placed on the layout.

Alternative plant layout

The GMA Principles 1 and 2 scores of the existing layout and the activity relationship analysis were used to improve the layout. Adjustment of the workstations was made and the new layout was re-assessed based on GMA Principles 1 and 2.

Results and discussion

Establishment of distinct hygiene zone (GMA Principle 1)

The overall score for the establishment of a distinct hygiene zone was 38.5% (Table 1). Of the six criteria of GMA Principle 1, two were satisfactory (S); hygienic zone drawings (item 1.01) and the location of restroom facilities (item 1.03). The separation of areas for high-risk zones was unsatisfactory (U) for workers (item 1.02), storage room for tools and spare parts (item 1.04), and storage areas for sanitation crews (item 1.06). Separation of quality laboratory between risk zones (item 1.05) was not applicable (N) due to the absence of a laboratory provided by the company. An in-house laboratory has been seen as space-consuming and costly to small plants such as FFF since this facility is non-compulsory in the Malaysia GMP requirement.

Table 1. Evaluation of sanitary design of FFF existing layout based on GMA scoring checklist tools.

No.	Criteria	Points available	FFF Plant	
			Score	Points awarded
	PRINCIPLE 1 – Establishment of Distinct Hygienic Zones in Facility			
1.01	Hygienic zones are clearly demarcated with colours or any easy identification markings on the facility drawings	25.0	S	25.0
1.02	Locker and lunch rooms for workers are segregated between risk zones (lower and high)	25.0	US	0.0
1.03	No restroom facilities are designed in high-risk zones	25.0	S	25.0
1.04	Storage areas for tools and spare parts are segregated between risk zones	25.0	US	0.0
1.05	Quality labs are segregated between risk zones	0.0	N	0.0
1.06	Storage areas for sanitation crews are segregated between risk zones	30.0	US	0.0
TOTAL POINTS FOR PRINCIPLE 1		**130.0**		**50.0 (38.5%)**
	PRINCIPLE 2 – Controlled Personnel and Material Flow to Reduce Hazards			
2.01	Facility is designed to promote controlled movement of workers and visitors	25.0	US	0.0
2.02	Facility is designed to promote controlled movement of contractors and maintenance workers	20.0	M	10.0
2.03	Facility is designed to promote sanitary delivery of packaging materials, ingredients, and rework into high-risk zones	25.0	M	12.5
2.04	Facility is designed to promote sanitary removal of trash from high-risk zones	30.0	US	0.0
TOTAL POINTS FOR PRINCIPLE 2		**100.0**		**22.5 (22.5%)**

S = Satisfactory; M = Marginal; US = Unsatisfactory; N = Not applicable

A low score in Principle 1 remarks poor physical segregation of hygienic zoning and this can increase the probability of hazards transfer within the facilities (AFFI Food Safety Zone, n.d). Prerequisite programs such as enforcement and application of hygienic measurements are crucial in reducing the occurrence of microbiological contamination during food processing (Mohamed-Noor *et al*., 2012).

Personnel and material flows (GMP Principle 2)

The worker and packaging and auxiliary materials flows were poorly controlled with a score of 22.5% (Table 1). The process of controlling worker and visitor's movement (item 2.01) and waste removal flow was unsatisfying (U) (item 2.04). An ideal production layout should be designed in a way that raw materials and workers are able to move through a linear path of increasing hygienic level zones to minimize cross-contamination in food processing plants (FAO, 2003). In the existing layout, the poor arrangement of workstations has led to an unnecessary complicated flow of materials. As seen in Figure 1, the location of the blast freezer and freezer 1 for unpacked FCCCP storage required workers to travel back to potentially cross-contaminating areas of production, mixing, washing, cooking, open cooling, filling chiller, and also cold storage areas. Due to time constraints during the production process, products that could not be packed immediately after blast freezing were placed in freezer 1 for a maximum of 2 days of storage. The unpacked product is exposed to cross-contamination as a result of this cross-movement.

Marginal satisfactory (M) scores were observed in items 2.02 and 2.03, where no separate pathway between hygiene zones was established for contractors and maintenance personnel, however strict hygiene practices were applied where they have to wear proper attire such as a hair net and shoe cover before entering the facility. All ingredients and materials also went through proper quality inspection before transfer to storage rooms. The location of the freezer and chiller for raw ingredients was poorly designed at the end of the pathway which could introduce the preparation area to the risk of cross-contamination. Sanitary removal of waste also was carried out without proper segregation according to zoning and waste flow from ‘clean’ to ‘dirty’ areas within the facility. Waste flow such as discarded packaging materials is required to be moved in the opposite direction of raw materials circulating from high hygiene to lower hygiene areas to avoid contamination risk and ensure products’ food safety (Moerman, 2016).

Activity relationship analysis

All pairs of relationships were assessed and each pair was assigned with a closeness rating; A, E, I, O, and U. Figure 2 shows the absolute need for receiving raw materials at the unloading bay (No.1) to be adjacency located to dry storage (No. 2) and raw material freezer (No.3). As a result, these close relationships were designated as A. The packaging area (No.13) is undesirable to be adjacent to the raw materials receiving area (No.1) since a high risk of cross-contamination can occur during the packaging of the final FCCCP product. Thus, these processes were designated as X. Similarly, the blast freezer (No. 11) was extremely undesirable to be closed to other processes and absolutely necessary to be adjacent to the production area (No.10), freezer 1 (No.12), and packaging area (No.13) since the processes had consequence toward each other and worked concurrently to minimize contamination of unpacked FCCCP products owing to mishandling during the production process. This result demonstrated the consideration of food safety requirements during activity relationship analysis.

The ARC was converted into TCR according to weight values of A (6), E (5), I (4), O (3), U (2), and X (1) (Fitriani *et al*., 2015). The data gathered was analyzed numerically to determine the most important workstation in the FCCCP process. The maximum TCR was used to start a new placement of workstations in the alternative layout design. In this study, the production area (No. 10) was selected as the starter based on its highest TCR of 43. The next workstation with an absolute necessary relationship to the production area was the filling chiller (No. 8), mixing area (No. 9), and blast freezer (No. 11) with TCR of 32, 31, and 32, respectively. The filling chiller (No. 8) and blast freezer (No. 11) were the workstations with the highest TCR. The blast freezer with the highest score of 6 was selected for the following placement. This algorithm continued to determine the remaining areas of the layout design and concurrently fulfill food safety requirements in the production process. The relationship between processes or workstations was presented in ARC (Figure 2). Few amendments were considered before the activity relationship analysis due to poor hygienic zone establishment in the existing layout and unhygienic practices during the production process.

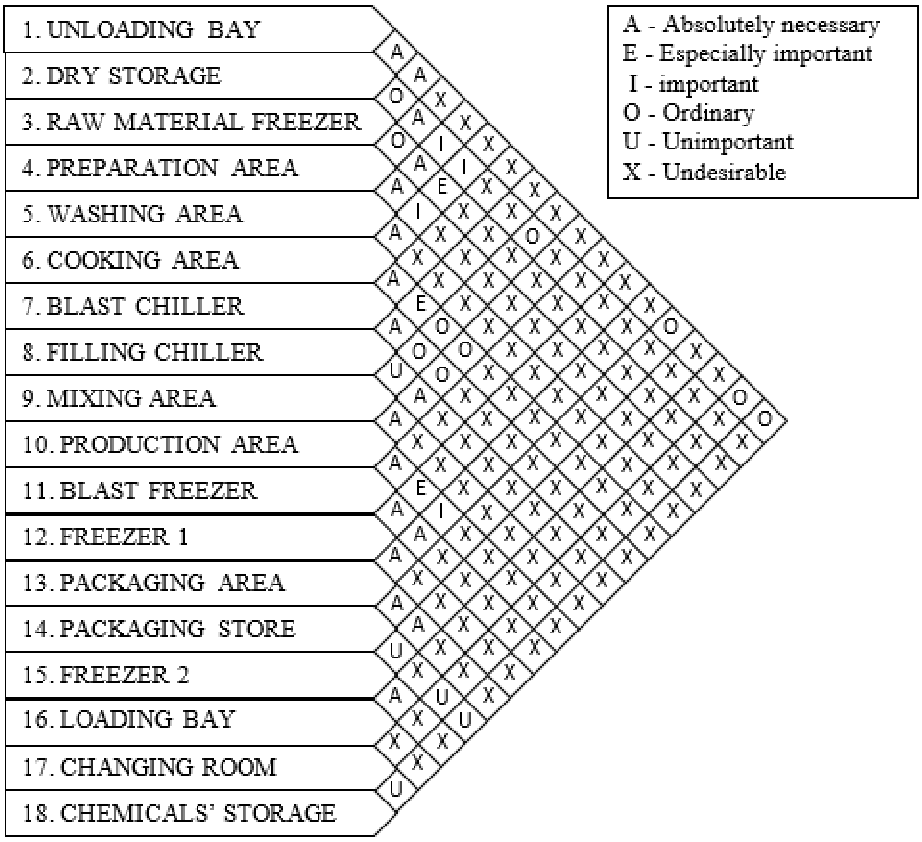

Figure 2. Activity relationship analysis of frozen crispy chicken curry puff processing.

This information is necessary for developing a new alternative layout design. Few workstations were renamed, two current workstations (dry storage and packaging stores) were combined, and two new workstations (preparation area and blast chiller) were proposed to promote the efficiency of FCCCP production and meet food safety requirements. The preparation room was introduced in the new layout to replace workstation (A), and a blast chiller was to replace workstation (B). Based on the existing layout evaluation, the FFF plant must consider these elements of food safety, hygienic zone in the facility areas, raw and auxiliary materials flow and workers' movement during the FCCCP production process, and adjacency of workstations according to the process flow. Due to these factors, the existing layout was deemed not ideal for the production process of FCCCP and subjected to be improved.

Alternative plant layout

Based on GMA scores on hygiene zone establishment, the personnel and raw and auxiliary materials flow, and the activity relationship diagram, the FFF current layout was improved. The new alternative layout is demonstrated in Figure 3. Cost and space were two major issues faced by most SMEs. Thus, the new layout suggested maintaining the current U-line layout since the FFF is located on an intermediate factory lot. The new layout attempted to make use of most of the space without requiring the company to consider site restructuration or expansion. According to Andrada and Biscocho (2019), the U-line layout design was found to reduce distance and production time significantly, as well as enhanced overall processing plant operation.

The blast chiller and preparation room in the alternative design were unavailable in the current facility. A blast chiller promotes a safe and hygienic cooling process of cooked filling in the production process within a reasonable time and temperature. The cooling process should be done in a short amount of time to reduce food exposure time at a Temperature Danger Zone (TDZ) of 5°C – 60°C (Wang and Zou, 2014). Therefore, the blast chiller was designed adjacent to the cooking area and filling chiller to minimize the filling movement and the cross-contamination risk. The preparation area with adequate hand washing stations was proposed in the layout to solve poor hygienic practices of peeling and cutting potatoes and onions and improve FCCCP's food safety. The location of the packing stores 1 and 2 also was rearranged in the new layout. Both storage areas located far from the packaging area were combined and linked with the packaging area. A door was designed at the side of the packaging storage room to facilitate sanitary delivery of packaging materials and to allow easy access without having to pass through many workstations. Similarly, both dry storage rooms were combined to facilitate smooth worker flow and product handling during the FCCCP processing.

New hygienic zoning was based on the classification of hygienic zones (standard, medium, and high) and corresponding production steps from FAO Good Hygiene Practices along with the food chain training tool (FAO, 2003). Sensitive ingredients and the risk of contamination on the food product were considered at every step of FCCCP's production process.

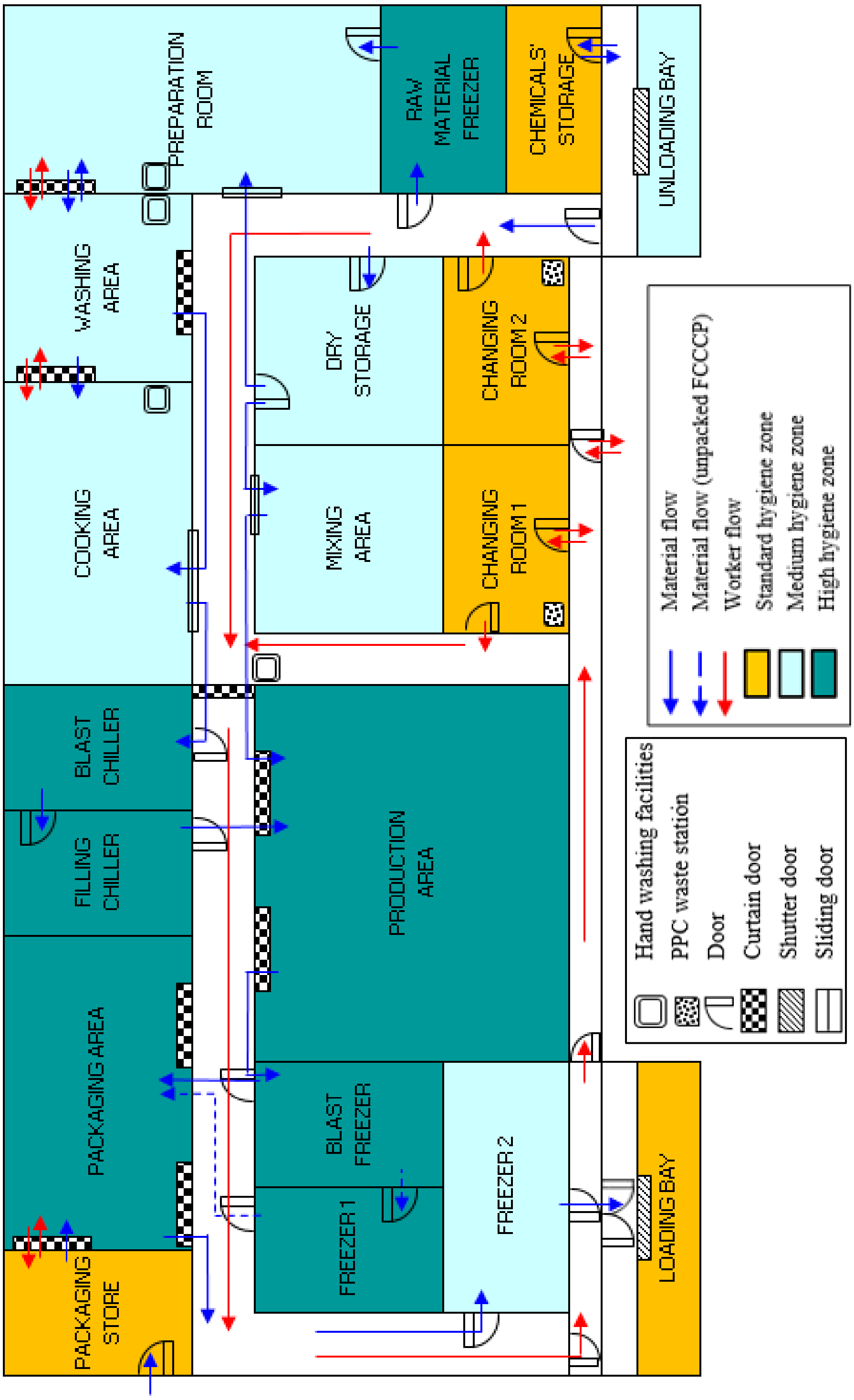

Figure 3. Proposed new layout of FFF frozen crispy chicken curry puff processing.

Establishing of hygiene zone and worker and product flow of the new layout was evaluated based on GMA Principles 1 and 2, and the scores were compared to the existing layout (Table 2).

Table 2 Evaluation of sanitary design of FFF existing and new layouts based on GMA scoring checklist tools.

No.	Criteria	Points available	FFF Plant		New layout	
			Score	Points awarded	Score	Points awarded
PRINCIPLE 1 - Distinct Hygienic Zones Established in The Facility						
1.01	Hygienic zones are clearly demarcated with colours or any easy identification markings on the facility drawings	25.0	S	25.0	S	25.0
1.02	Locker and lunch rooms for workers are segregated between risk zones (lower and high)	25.0	US	0.0	M	12.5
1.03	No restroom facilities are designed in high-risk zones	25.0	S	25.0	S	25.0
1.04	Storage areas for tools and spare parts are segregated between risk zones	25.0	US	0.0	S	25.0
1.05	Quality labs are segregated between risk zones	0.0	N	0.0	N	0.0
1.06	Storage areas for sanitation crews are segregated between risk zones	30.0	US	0.0	M	15.0
TOTAL POINTS FOR PRINCPLE 1		**130.0**		**50.0 (38.5%)**		**102.5 (78.8%)**
PRINCIPLE 2 – Controlled Personnel and Material Flow to Reduce Hazards						
2.01	Facility is designed to promote controlled movement of workers and visitors	25.0	US	0.0	S	25.0
2.02	Facility is designed to promote controlled movement of contractors and maintenance workers	20.0	M	10.0	M	20.0
2.03	Facility is designed to promote sanitary delivery of packaging materials, ingredients, and rework into high-risk zones	25.0	M	12.5	S	25.0
2.04	Facility is designed to promote sanitary removal of trash from high-risk zones	30.0	US	0.0	S	30.0
TOTAL POINTS FOR PRINCIPLE 2		**100.0**		**22.5 (22.5%)**		**90.0 (90%)**

S = Satisfactory; M = Marginal; US = Unsatisfactory; N = Not applicable

Table 2 shows that the new layout design scores high marks under principles 1 and 2; 78.8% and 90% as to the existing layout. The new layout attained a satisfactory (S) score in the clear demarcation of hygienic zoning and segregation of areas where high hygiene level workstations were arranged according to ARC and located together at the left of the plant. Utilities and tools used in high hygiene level areas were separated and color-coded. Storage facilities such as racks, cabinets, or containers that comply with GMP requirements were suggested to be placed at selected workstations within different zones to minimize contamination risk from standard and medium to high hygiene workstations. The new layout scores marginal satisfactory (M) for items 1.02 and 1.06. A separate locker and lunchroom were unavailable in the layout due to space constraints. However, they were segregated from the production area to minimize the contamination risk of the products. Other than that, the new alternative layout provides new facilities such as a separate change room for high hygiene areas (change room 1) and hand wash stations. Different travel pathways and access to lower and high hygiene zone areas were designed to avoid the risk of contamination and a mix of worker traffic from both zones. Workers from standard and medium hygiene areas are required to wash hands and renew personal protective clothing (PPC) such as gloves and apron before accessing higher hygiene areas to avoid the re-contamination of unpacked FCCCP by workers from lower hygiene workstations such as the raw materials preparation area (Hasnan *et al*., 2019). Due to that, hygiene facilities such as a hand wash station are important to be next to any workstation where workers travel from a low-risk to a high-risk area. Each changing room also was provided with a PPC waste station. Workers must remove their disposable PPC at the station and leave their footwear at a dedicated rack in the room as they leave the production area for a break or restroom visit outside the production plant. Workers resuming work must follow the same operational sequence with a new disposable PPC and footwear provided in the changing room.

Evaluation of GMA principle 2; personnel and product flow design of new layout provides a satisfactory (S) score in three out of four criteria; movement of worker (2.01), sanitary delivery of materials (2.03), and removal of trash (2.04) compared to existing layout design (Table 2). Controlled movement of contractors and maintenance workers is marginal satisfying (M) as existing layout since they share the same pathway as visitors. One of the most significant features in the new alternative layout design was the new placement of workstations. Raw material storages (dry storage and raw material freezer) were positioned near the unloading bay area to implement one way of worker, and raw and auxiliary material flows from the unloading bay to the loading bay without any crisscrossing or backward movement. Sanitary waste removal also was implied in the layout. Waste containers from high hygiene zones are not advisable to travel through different hygiene zones due to the risk of contamination (Holah, 2014; Hasnan *et al*., 2019). A waste trolley is suggested to promote efficient and sanitary waste transfer from the high hygiene to lower hygiene zones (medium and standard) before being deposited outside the plant at the temporary waste station. The waste will be daily transferred to the central disposal bins using a different trolley. Adequate drainage and proper waste piping system also were suggested for sanitary wastewater disposal.

Conclusions

This study provides an insight into an inefficient layout design of a SME producing frozen food in Malaysia. The layout has design issues that do not meet HACCP requirements and food safety prerequisites such as GHP. The new suggested layout based on the proper establishment of the hygienic zone, worker and product flow, and activity relationship analysis was found to be essential in resolving the layout issues, establishing hygienic food operations, and enhancing the safety of processed foods for the SMEs. The results also could provide references in food manufacturing layout design literature and industries, contributing to safe and hygienic food production of high-quality products.

Acknowledgments

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