International Journal of Production Research
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tprs20

Integration of occupational health and safety in the facility layout planning, part II: design of the kitchen of a hospital

Afrooz Moatari-Kazerouni[a], Yuvin Chinniah[a] & Bruno Agard[a]
[a] Department of Mathematical and Industrial Engineering, Ecole Polytechnique de Montréal, Montreal, Canada
Published online: 27 Oct 2014.

To cite this article: Afrooz Moatari-Kazerouni, Yuvin Chinniah & Bruno Agard (2015) Integration of occupational health and safety in the facility layout planning, part II: design of the kitchen of a hospital, International Journal of Production Research, 53:11, 3228-3242, DOI: 10.1080/00207543.2014.970711

To link to this article: http://dx.doi.org/10.1080/00207543.2014.970711

International Journal of Production Research, 2015
Vol. 53, No. 11, 3228–3242, http://dx.doi.org/10.1080/00207543.2014.970711

Taylor & Francis
Taylor & Francis Group

Integration of occupational health and safety in the facility layout planning, part II: design of the kitchen of a hospital

Afrooz Moatari-Kazerouni, Yuvin Chinniah and Bruno Agard*

Department of Mathematical and Industrial Engineering, Ecole Polytechnique de Montréal, Montreal, Canada

(*Received 13 May 2014; accepted 17 September 2014*)

Facility layout design has an important effect on the performance of manufacturing systems. It intends to determine relative location of departments and machines within a plant. A good layout design must ensure that a set of criteria and objectives are met and optimised, e.g. area requirements, cost, communication and safety. The most common objective used in facility planning methods is to minimise the transportation cost. However, factors such as the plant safety, flexibility for future design changes, noise and aesthetics must be considered as well. In this paper, a case study is carried out to investigate the safety concerns in facility layout design. In this regard, a facility layout planning methodology, integrating occupational health and safety (OHS) is presented. This methodology considers transportation cost as well as safety in the facility design. By this means, OHS issues are considered at the design stage of the facility. In other words, this research demonstrates the improvements in the layout design by integrating safety aspects.

Keywords: facility planning models; layout design; occupational health and safety (OHS); risk estimation

1. Introduction

Manufacturing systems are means of describing the combination of resources and methods inherent to manufacturing activities (Lefrancois and Montreuil 1994). A manufacturing company is a complex human, machine, environment and organisation system. For productive and effective functioning of such companies, management should ensure optimum functioning of the system components. Although, there is a growing concern to improve productivity, safety and quality in the manufacturing companies, many industries neglect facility design.

Plant layout deals with the arrangement of the most valuable assets of the companies, such as the departments and machines (Islier 1998). It aims to obtain the most effective facility arrangements and minimise the material handling costs (De Alvarenga and Negreiros-Gomes 2000). In other words, the facility designer attempts either to maximise an adjacency measure, minimise the total cost of material handling or optimise some combination of the two (Kochhar 1999). It is reported that the manufacturing industry is one of the most dangerous sectors for employees, given the frequency and severity of occupational accidents (Silvestri, De Felice, and Petrillo 2012).

An improper workplace design, including poor human–machine system design and problems with workstations, are common issues raised in manufacturing industries. These result in workplace hazards, poor workers' health, injuries linked to equipment and disabilities (Shikdar, Al-Araimi, and Omurtag 2002). Occupational health and safety (OHS) regulations are aimed primarily at improving conditions in workplaces (Saari et al. 1993). They improve the performance of sub-standard companies as well as the initially safer companies. However, workplaces need to be compatible with the types of task to be conducted and human characteristics, so that risks to the health and safety of workers and the potential for human error is reduced to as low as reasonably practicable (Hadke and Gupta 2013). At least 250 million occupational accidents occur every year worldwide which result in 335,000 fatalities (ILO 2012). OHS should be included in designing and modifying a facility. OHS contributes to product conformity, by ensuring that the conditions necessary for thoroughly carrying out tasks are met (De Oliveira Matias and Coelho 2002). It will also result in a positive effect in promoting employees' productivity and quality of product or work; increase efficiency and productivity of the company and decrease costs.

Preventing OHS hazards is best achieved at the design stage of a facility layout. In order to have a good layout, it is important to promote safe and efficient operations, minimise travel time, decrease material handling, and avoid obstructing material and equipment movements (Karray et al. 2000). Methods like hazard analysis and risk assessment can be

*Corresponding author. Email: bruno.agard@polymtl.ca

used for mitigating the risks to an individual at the workplace facility (Meswani 2008). Potential hazards in the layout design must be identified. However, integrating OHS in facility planning in manufacturing industries has not been extensively studied and is often neglected by facility designers.

The main objective of this paper is to present a case study showing a facility layout methodology which integrates OHS. The case study is based on the real re-designing of the layout of a hospital kitchen in Montreal.

The next section presents the literature review, mainly focusing on the relationship between facilities layout design and OHS. Section 3 describes the research scope and contribution. Section 4 exposes the proposed methodology and the case study. The improvements that have been achieved will be discussed.

2. Literature review

Studies have shown positive effects of applying OHS principles in companies. Nevertheless, the relationship between facilities layout design and OHS is not researched extensively. Broberg (2011) reports on the trial of the workspace design concept in a case involving the design and implementation of a new mixing technology in an industrial plant. Hadke and Gupta (2013) examine the employee's workplace environment and evaluate the work performance at normal and abnormal condition at a nuclear power plant. They suggest how to optimise the situations in terms of work place design and optimise the work environmental parameters. Tam, Zeng, and Deng (2004) examine the status of safety management in the Chinese construction industry, explore the risk-prone activities on construction sites and identify factors affecting construction site safety. Hall-Andersen and Broberg (2013) researched on how companies respond to new safety regulations; while an engineering design case is analysed using the theoretical concepts of boundary objects and intermediary objects. Benjaoran and Bhokha (2010) developed an integrated system for safety that incorporates safety measures into the design of plants. They formulated rule-based algorithms to help automatically identify hazards resulting from working at certain heights and advise proper safety measures. Aksorn and Hadikusumo (2008) identified and ranked 16 critical success factors of safety programme implementation based on their degree of influence. Moatari-Kazerouni, Chinniah, and Agard (2014b) proposes a facility layout planning methodology which integrates the OHS features in the early design of a facility layout. The model considers transportation cost in the facility as well as safety concerns. Behm (2005) determined a link between fatalities and the design for construction safety by reviewing 224 fatality investigation reports. The research by Ho, Xu, and Dey (2010) aimed at better understanding the relationships between lean, the working environment and its effects on employee health, job satisfaction and commitment. Melzner et al. (2013) introduce an advanced design and planning approach for construction safety. It detects potential fall hazards and recommends safety protective equipment based on predefined rule sets. Kleban, Luger, and Watkins (1996) developed a computer programme that assists manufacturing engineers and environmental reviewers in assessing environmental consequences of their manufacturing decisions.

Shikdar and Sawaqed (2003) developed a computer software package as a self-assessment tool for evaluating ergonomic improvement potential of production systems by engineers, managers and safety professionals. Ergonomic conditions in small manufacturing industries are investigated by Shikdar and Al-Araimi (2001). Old machines, poorly designed workplaces, lack of systematic planning, layout and organisation, unsafe working conditions and poor environment are commonly found in these industries. Neumann et al. (2002) provide empirical evidence suggesting that production system design decisions, guided by technical considerations, result in negative ergonomic consequences.

The majority of previous research on facility layout design focused upon optimising costs and closeness relations. Qualitative factors such as the plant safety, flexibility of layout for future design changes, noise and aesthetics must be considered as well.

3. Research scope and contribution

In Moatari-Kazerouni, Chinniah, and Agard (2014a), a risk estimation method was developed. In Moatari-Kazerouni, Chinniah, and Agard (2014b), the method for integrating OHS in facility planning using risk estimation was explained. In this paper, a case study which shows the integration of OHS in facility planning is presented. A new layout design for a hospital kitchen which not only would be cost-efficient but also considers different safety issues existing in the current layout is developed. Relevant information for this study was gathered through observations and interviews with the kitchen personnel. Several observation sessions during various working hours of the kitchen were carried out. Interviews with the kitchen personnel shed light on existing safety concerns in the kitchen.

This layout design methodology would value OHS factors and consider their relative importance to cost when assigning locations to the various departments.

4. Integration of OHS in facility planning

4.1 *Initial situation of the hospital*

The case study was conducted in the kitchen of a hospital where the food is prepared, stored and distributed to every patient. The kitchen was originally design in 1907. Over time, different improvements and modifications were executed without an overall coordination. Recently, renovation of the kitchen layout was suggested to provide additional services such as the room service for supporting specific food requests at different times. The new concept of room service requires changes in the distribution and production areas. Different equipment had to be renewed and the facility layout had to be modified to satisfy the new concept. Therefore, changes in the layout design of the kitchen seemed necessary and the hospital has decided to update all the food service area.

A sketch of the current layout of kitchen is shown in Figure 1. The kitchen consists of different sections: office area, production area (food preparation), distribution centre including a conveyor and workstations for mounting food trays for patients, service area for weighing portions and selecting ingredients for recipes, section for pastries, area for washing the trolleys (used for transporting trays), area for dismounting the used trays collected from patients, area for washing the dishes and trays, storage and warehouse areas i.e. refrigerated rooms for perishables and storage room with racks for non-perishables items.

The current layout of the kitchen is mainly designed based on the flow of products (foods) throughout the facility as well as the efficient closeness of department according to the cost factor. There are safety issues in regards to the kitchen layout which require re-designing and changes in the location of different departments. These will involve the proposition of a new layout design based on not only the cost factor but also OHS issues. The methodology to integrate OHS in facility planning is elaborated in the following sections.

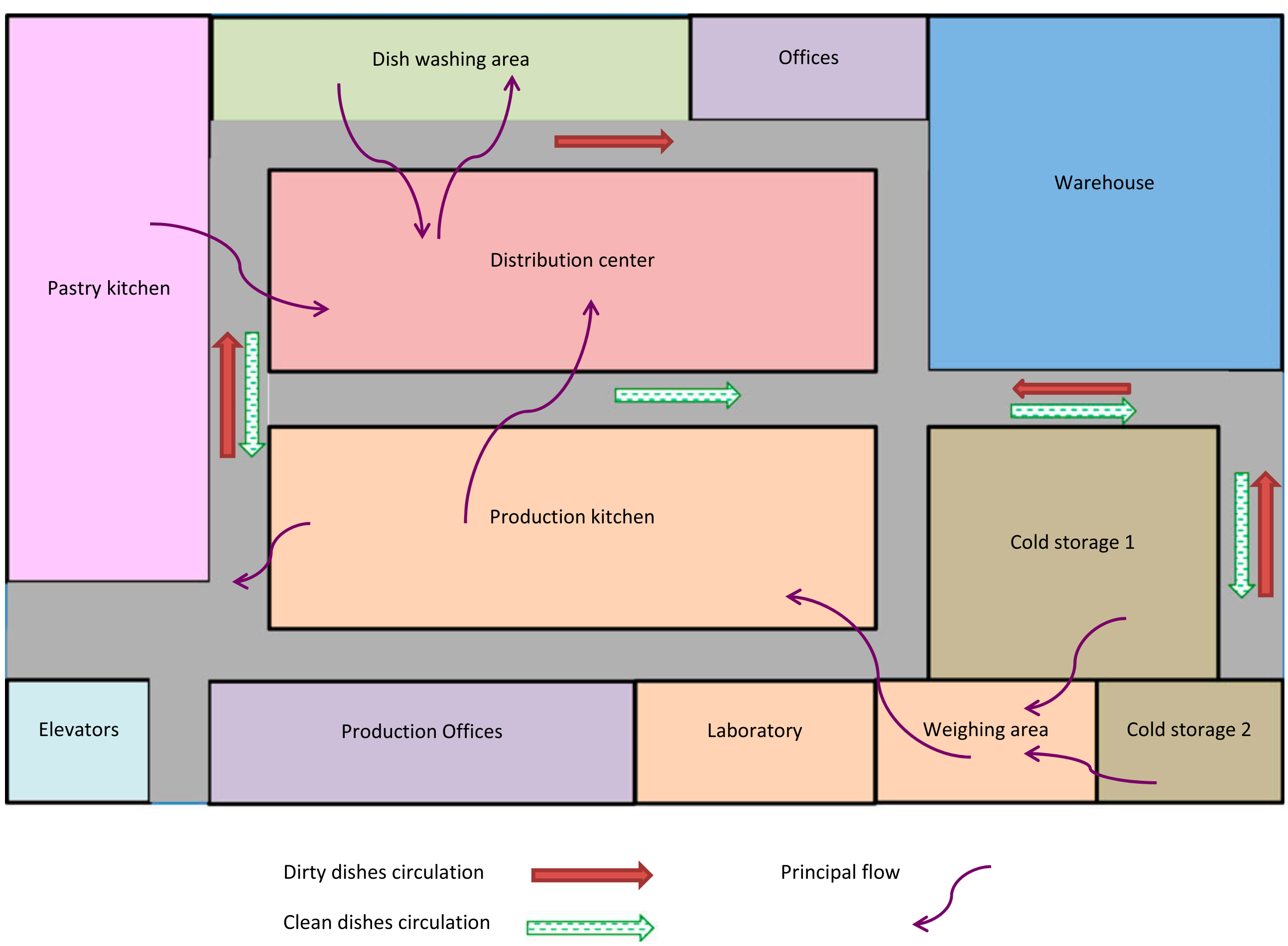

Figure 1. Current layout design of the kitchen.

The kitchen has 12 departments and 9 hall ways. The total available space is considered to be 13,000 ft^2, and the cost of carrying material per unit distance is one. The 'from-to' chart is as shown in Table 1. As an example, the flow from the 'dish washing area' to 'offices' department is 146 and 0 from the 'offices' to 'dish washing area'.

The current layout of the kitchen has flaws from facilities layout and OHS points of view. The 'from-to' chart reveals the high transportation of product and services between 'distribution centre' and the elevator as well as the 'dish washing area' and the elevator. Therefore, locating the elevator to these two departments could be considered to reduce the material handling and transportation cost. In terms of OHS, material handling between the 'distribution centre' and the 'production kitchen' can lead to hazards.

4.2 *Methodology for integrating OHS in facility planning*

Muther (1973) developed a layout design procedure named as Systematic Layout Planning (SLP). This process is widely used by engineers for facility planning projects and involves optimising three fundamental aspects of relationships, space and adjustment. In SLP process, based on the input data and an understanding of the roles and relationships between activities, a from-to chart and an activity relationship chart are probed; consequently, a relationship diagram is developed. Considering the space required and the available space, a space relationship diagram is configured. Based on the modifying considerations and practical limitations, a number of layout alternatives are developed and evaluated. The preferred layout is then identified and recommended (Tompkins et al. 2010). The methodology presented in this paper is partly based on the relationship diagramming process presented in the SLP process.

The methodology, explained in detail in Moatari-Kazerouni, Chinniah, and Agard (2014b), consists of three steps. First step concentrates on the traditional cost factors. The cost matrix is calculated by multiplying 'number of loads from the "from-to" chart' by 'rectangular distance between departments from the distance matrix' by 'cost per unit distance'. Five cost categories are defined according to their relative cost portions. Applying these categories, the relative importance in closeness of the departments based on the cost factor, is demonstrated as a cost relationship diagram.

The second step evaluates layout design by considering OHS aspects. Risk scenarios need to be identified. For these scenarios, quantitative levels of the five risk parameters is evaluated, i.e. severity of harm, frequency of exposure to the hazard, duration of exposure to the hazard, probability of occurrence of a hazardous event, and technical and human possibility of avoiding or limiting the harm. For each scenario, the risk value is calculated (Equation (1)) and the safety relationship diagram is designed.

The third step explains how the former layout can be adjusted based on the OHS aspects by using the safety-cost relationship diagram. The layout is improved by exchanging the positions of departments. The department pairs with the lowest risk rank are considered as candidates for being exchanged. As a result, the layout design is improved by including OHS aspects. This is assured by determining changes in the total cost value of layout.

In designing a new layout, this methodology suggests considering cost factor, followed by the safety aspect. Details of each step of the model are explained throughout the case study example in the following paragraphs.

4.2.1 *Step 1 – Material handling and transportation cost factor*

(1) Develop the distance matrix by calculating the distance between departments. The distance matrix for the case study is shown in Table 2.
(2) Calculate cost matrix by multiplying 'flow of material from the "from-to" chart' by 'distance from the distance matrix' by 'cost of carrying any material'.

The cost matrix for the case study is calculated by multiplying Table 1 by Table 2 and is illustrated in Table 3.

(3) Calculate the total cost value by using Equation (1).

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} d_{ij} c_{ij} \tag{1}$$

where i and j are the departments, m is the total number of departments, f_{ij} is the flow of material from the 'from-to' chart, d_{ij} is the distance from the distance matrix and c_{ij} is the cost of carrying any material.

The total cost value for the case study equals to \$ 113 795.

Table 1. 'From-to' chart of the kitchen.

From/To	offices	dish washing area	warehouse	pastry kitchen	distribution centre	production kitchen	cold storage 1	elevators	laboratory	production offices	weighing area	cold storage 2
offices		0	100	120	230	200	90	10	50	210	30	10
dish washing area	146		197	40	381	160	30	300	95	43	0	0
warehouse	197	20		210	87	315	0	106	0	164	0	0
pastry kitchen	51	270	321		380	130	90	100	20	63	14	0
distribution centre	159	396	20	11		48	270	397	35	134	0	120
production kitchen	103	195	16	183	379		294	84	30	142	22	17
cold storage 1	18	56	0	81	215	200		97	61	32	282	0
elevators	10	350	362	347	295	67	133		14	19	0	75
laboratory	39	160	0	0	195	244	32	0		51	0	0
production offices	81	0	161	0	239	270	99	0	17		16	0
weighing area	15	110	0	67	33	202	0	0	0	0		0
cold storage 2	0	190	0	51	70	77	0	0	0	0	219	

Table 2. Distance matrix of the kitchen.

Distance	offices	dish washing area	warehouse	pastry kitchen	distribution centre	production kitchen	cold storage 1	elevators	laboratory	production offices	weighing area	cold storage 2
offices		3	5.75	9.25	4.5	8.25	10.25	14.75	9.5	12.25	11.25	14.5
dish washing area	3		8.75	6.25	3.5	7.25	13.25	11.75	11.5	9.25	14.25	17.5
warehouse	5.75	8.75		11.5	6.75	10.5	5	17	11.75	14.5	7	6.75
pastry kitchen	9.25	6.25	11.5		4.75	6	12	5.5	10.25	7.5	13	16.25
distribution centre	4.5	3.5	6.75	4.75		3.75	9.75	10.25	8	7.75	10.75	14
production kitchen	8.25	7.25	10.5	6	3.75		6	6.5	4.25	4	7	10.25
cold storage 1	10.25	13.25	5	12	9.75	6		12	6	8.75	4	4.25
elevators	14.75	11.75	17	5.5	10.25	6.5	12		5.25	2.5	8	11.25
laboratory	9.5	11.5	11.75	10.25	8	4.25	6	5.25		2.75	2.75	6
production offices	12.25	9.25	14.5	7.5	7.75	4	8.75	2.5	2.75		5.5	8.75
weighing area	11.25	14.25	7	13	10.75	7	4	8	2.75	5.5		3.25
cold storage 2	14.5	17.5	6.75	16.25	14	10.25	4.25	11.25	6	8.75	3.25	

Table 3. Cost matrix of the kitchen.

Cost Matrix	offices	dish washing area	warehouse	pastry kitchen	distribution centre	production kitchen	cold storage 1	elevators	laboratory	production offices	weighing area	cold storage 2
offices	0	0	575	1110	1035	1650	922.5	147.5	475	2572.5	337.5	145
dish washing area	438	0	1723.75	250	1333.5	1160	397.5	3525	1092.5	397.75	0	0
warehouse	1132.75	175	0	2415	587.25	3307.5	0	1802	0	2378	0	0
pastry kitchen	471.75	1687.5	3691.5	0	1805	780	1080	550	205	472.5	182	0
distribution centre	715.5	1386	135	52.25	0	180	2632.5	4069.25	280	1038.5	0	1680
production kitchen	849.75	1413.75	168	1098	1421.25	0	1764	546	127.5	568	154	174.25
cold storage 1	184.5	742	0	972	2096.25	1200	0	1164	366	280	1128	0
elevators	147.5	4112.5	6154	1908.5	3023.75	435.5	1596	0	73.5	47.5	0	843.75
laboratory	370.5	1840	0	0	1560	1037	192	0	0	140.25	0	0
production offices	992.25	0	2334.5	0	1852.25	1080	866.25	0	46.75	0	88	0
weighing area	168.75	1567.5	0	871	354.75	1414	0	0	0	0	0	0
cold storage 2	0	3325	0	828.75	980	789.25	0	0	0	0	711.75	0

Table 4. Cost categories.

Cost Categories	Ranks	Cost Portions %
Category 1	U- unimportant	< 50%
Category 2	O- ordinary closeness	> 40%
Category 3	I- important	> 25%
Category 4	E- especially important	> 12%
Category 5	A- absolutely necessary	> 5%

(4) Define the five cost categories according to their relative cost portions, where Category 5 contains the highest cost values and Category 1 the lowest; corresponding to Table 4.

The cost matrix table, demonstrated in Table 5, is upper-triangle and colour-coded based on the different categories identified in Table 4.

(5) Demonstrate the relative importance in closeness of the departments based on the cost factor by illustrating a cost relationship diagram. Figure 2 shows the cost relationship diagram for the current layout of kitchen (Moatari-Kazerouni, Chinniah, and Agard 2014a).

4.2.2 *Step 2 – OHS evaluation*

(6) Develop risk scenarios for the initial layout design.

Four risk scenarios are identified in the initial layout of hospital kitchen.

Scenario 1: The first scenario indicates the noise hazard which would be considerable when the ‘offices or production offices’ and ‘dish washing area’ departments will be located close to each other. The hazard is from the noise caused by the dish washing conveyor and the noise generated by the metallic utensils. It can be very disturbing for the office workers in continuous exposure.
Scenario 2: Interruptions in the material handling between the ‘distribution center’ and ‘production kitchen’ departments is a movement hazard which can be a danger for workers, e.g. while carrying boiling water one stumbles upon or collide with another worker.
Scenario 3: The dish washing machine generates a lot of heat. It can be harmful for the worker specifically those who work at the cold storage area. A sudden temperature change from the extreme cold (in the cold storage area) to the hot temperature (of dish washing and dryer machine) is a hazard for workers. This heat hazard is considerable when the ‘dish washing area’ and ‘cold storage 1 or 2’ departments are located close together.
Scenario 4: Chemicals are stored in the warehouse; therefore, fumes are possible from chemicals being in contact with heat generated in the production and distribution area. This indicates the chemical hazard between ‘warehouse’ and ‘distribution center or production kitchen’ departments.

(7) For each hazardous situation, identify the qualitative risk level for each of the five risk parameters as addressed in Moatari-Kazerouni, Chinniah, and Agard (2014a). These parameters, which were identified through an extensive literature review, are namely: (1) severity of harm, (2) frequency of exposure to the hazard, (3) duration of exposure to the hazard, (4) probability of occurrence of a hazardous event and (5) technical and human possibility of avoiding or limiting the harm. Since the proposed risk parameters are qualitatively scaled, they were transformed into quantitative measures. A rating system is used by which quantitative values (1–5) are assigned to the levels of each risk parameter.

(8) For each hazardous situation, calculate the risk value:

$$\text{Risk value (R)} = \text{Severity of harm (S)} \times \text{Probability of occurrence of harm (Ph)}$$

Table 5. Cost matrix of the hospital kitchen based on the cost categories.

Cost Matrix	offices	dish washing area	warehouse	pastry kitchen	distribution centre	production kitchen	cold storage 1	elevators	laboratory	production offices	weighing area	cold storage 2
offices		438	1707.75	1581.75	1750.5	2499.75	1107	295	845.5	3564.75	506.25	145
dish washing area			1898.75	1937.5	2719.5	2573.75	1139.5	7638	2932.5	397.75	1567.5	3325
warehouse				6106.5	722.25	3475.5	0	7956	0	4712.5	0	0
pastry kitchen					1857.25	1878	2052	2459	205	472.5	1053	828.75
distribution centre						1601.25	4728.75	7093	1840	2890.75	980	2660
production kitchen							2964	981.5	1164.5	1648	1568	963.5
cold storage 1								2760	558	1146.25	1128	0
elevators									73.5	47.5	0	843.75
laboratory										187	0	0
production offices											88	0
weighing area												711.75
cold storage 2												

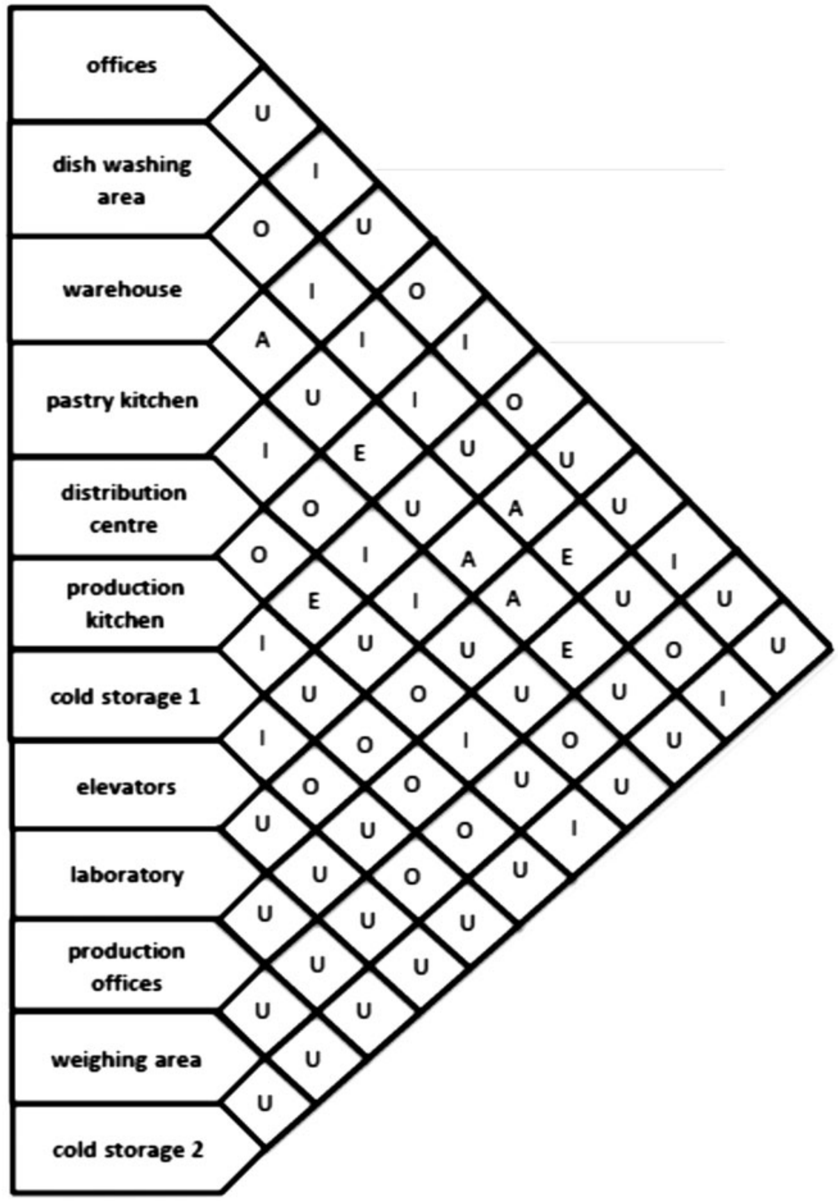

Figure 2. Material handling and transportation cost relationship diagram.

$$
\begin{aligned}
\text{Probability of occurrence of harm (Ph)} = {} & \text{Frequency of exposure to the hazard (Exf)} \\
& + \text{Duration of exposure to the hazard (Exd)} + 2 \\
& \times \text{Probability of occurrence of a hazardous event (Pe)} \\
& + \text{ Possibility of avoidance (A)}
\end{aligned}
$$

(9) For each risk scenario, identify the corresponding interval for the risk value according to the conversion table (Risk value evaluation) proposed in Moatari-Kazerouni, Chinniah, and Agard (2014b).

Since the maximum number obtained from the aforementioned equation is 125 and the minimum is 1, in this paper, the range of risk ranks were divided to five equal categories from 1 to 125. However, designers can adjust the risk categories to reflect the realities of the manufacturing plants and their preferences for tolerable risk. These categories are ranked by scales of 1–5. A higher risk value indicates that it is dangerous to place the departments close to each other.

Table 6. Scenario analysis.

SCENARIOS	S	Ph				Risk Value R=S*(Exf+Exd+2*Pe+A)	Safety Ranks
		Exf	Exd	Pe	A		
Scenario 1	4	5	5	3	4	**80**	2
Scenario 2	4	5	5	3	5	**84**	2
Scenario 3	2	5	5	3	4	**40**	4
Scenario 4	5	5	5	4	4	**110**	1

The evaluation of scenarios for this case study is shown in Table 6. This estimation is based on the observations of different tasks carried out in the kitchen.

(10) Demonstrate the relative importance in closeness of the departments based on the safety factor as a safety relationship diagram.

Figure 3 illustrates the OHS relationship diagram for the current layout of kitchen (Moatari-Kazerouni, Chinniah, and Agard 2014a).

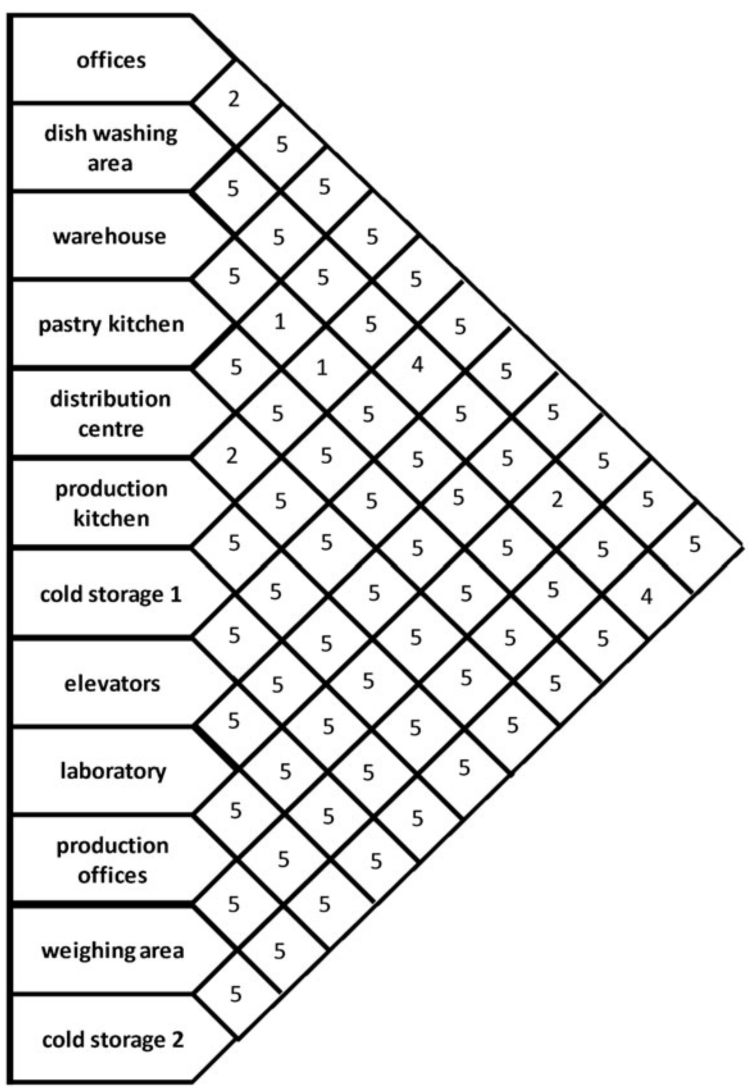

Figure 3. OHS relationship diagram.

4.2.3 *Step 3 – Layout improvements considering OHS aspects*

(11) Design a safety-cost relationship diagram.

As it is mentioned previously, this methodology considers cost factor, followed by the safety aspect for choosing the department-pairs to enter the layout. Other issues such as the priorities set by the company or the facility planner's opinion can also influence the choice.

By comparing the ranks assigned to cost (Figure 2) and safety (Figure 3) factors, the safety-cost relationship diagram for the current layout of kitchen is illustrated in Figure 4 see Moatari-Kazerouni, Chinniah, and Agard (2014a) for more details.

The closeness relationships between (1) 'office' and 'dish washing area', (2) 'warehouse' and 'distribution centre', (3) 'warehouse' and 'production kitchen', (4) 'dish washing area' and 'cold storage 1' and (5) 'dish washing area' and 'production offices' are changed because of the safety factor. For these departments, the ranks assigned to the OHS issues were more important than the cost factors. Therefore, the closeness relationships are decided based on the safety reasons.

For the closeness relationship among 'dish washing area' and 'cold storage 2', both safety and cost factors are important. However, the rank assigned to the cost factor was higher than the OHS concerns. Therefore, the closeness relationship between these two departments is determined according to the cost reason.

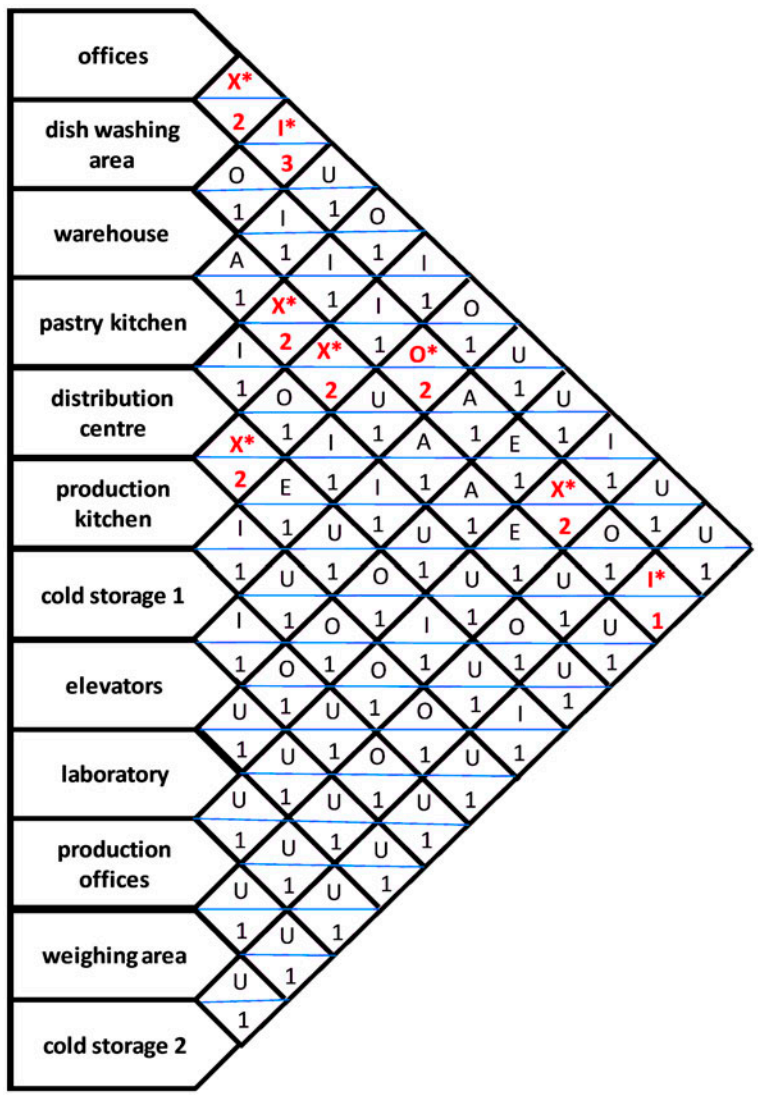

Figure 4. Safety-cost relationship diagram.

Furthermore, the relationship between the 'offices' and 'warehouse' is set because of the management point of view. There is a high flow of information between these two departments. Therefore, locating them closer together can be beneficial.

For the rest of the departments, the closeness relationships are grounded because of the cost reason, since the ranks are higher for the cost than the safety factors.

(12) Design a new layout based on the safety-cost relationship diagram (Figure 4).
(13) Make improvements by exchanging pairs of departments iteratively until no further improvement is possible.

In this concern, total cost value of the new layout should be calculated based on Equation (1). If the cost value for the new layout is less than the cost of initial layout, new layout is the final layout improvement. Otherwise, department pairs with the lowest risk rank from OHS relation diagram will be selected. A new layout will be developed by exchanging these department pairs and the cost value will be calculated again.

The new layout suggested for the kitchen is shown in Figure 5. This layout is designed based on the safety-cost relationship diagram and consider OHS issues as important as the cost-efficiency objective. In this layout, the location of the 'dish washing area' is changed by the 'offices', while 'production offices' is switched by the 'laboratory' department. In this new layout design, the 'offices' are located further from the 'dish washing area' because of the undesirable closeness relationship (X) among them due to the safety issues (Scenario 1). However, the 'offices' department is still enough close to the 'warehouse' to satisfy their important closeness relationship (I) in regard to the flow of information among them. Changing the location of the 'dish washing area' also increased the distance among 'dish washing area' and 'cold storage 1 or 2' departments. This further distance among the 'dish washing area' and 'cold storage 1 or 2' departments improves the temperature differences between these departments and decreases the heat safety concerns of Scenario 3.

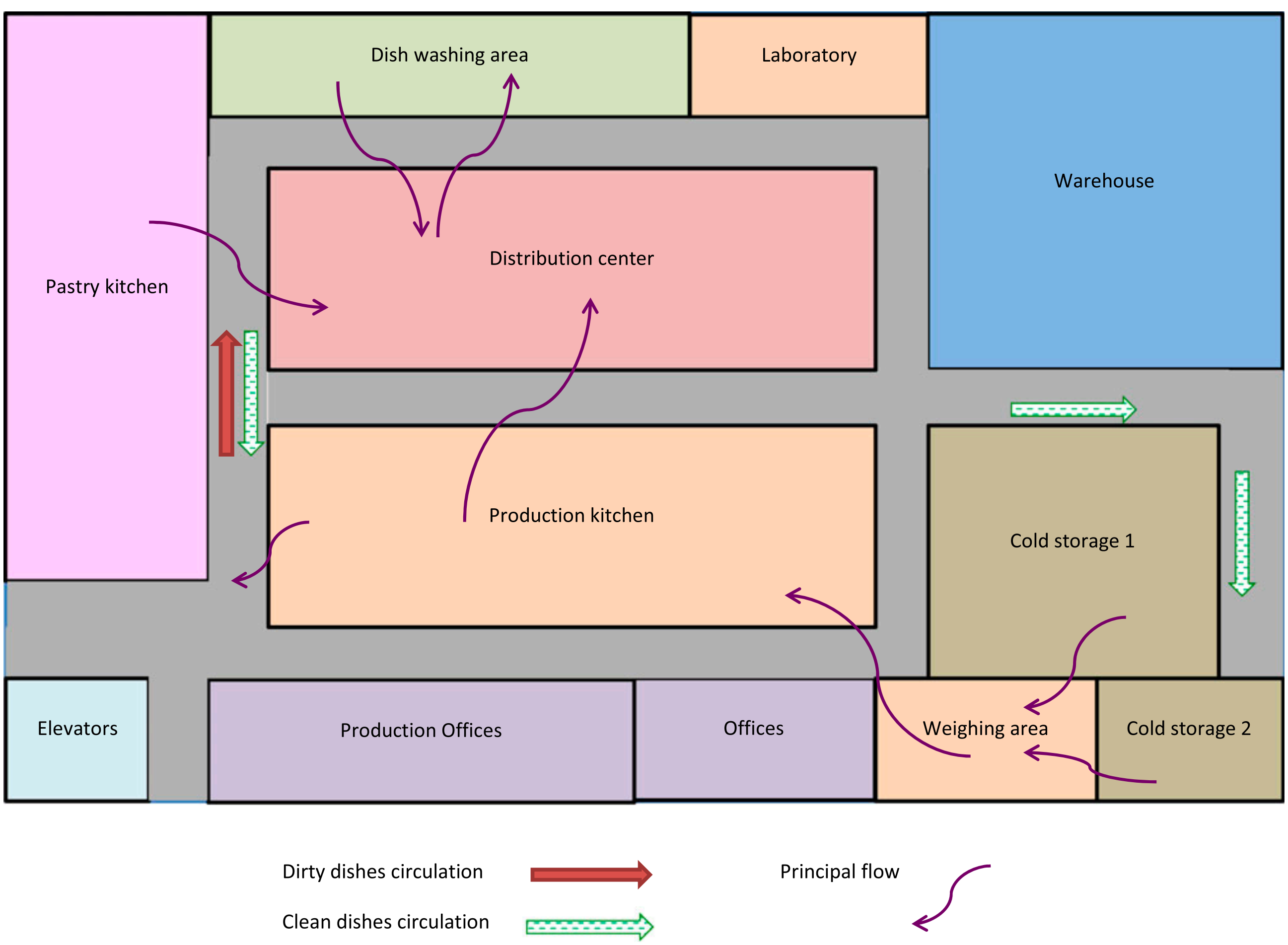

Figure 5. New layout design of the kitchen.

Table 7. Comparison of old and new layout designs.

		Old layout design	New layout design
OHS factor	Scenario 1	2 (safety rank)	I
	Scenario 2	3	NC
	Scenario 3	4	I
	Scenario 4	1	NC
Cost factor	Total cost of layout design	$ 113 795	$ 110 196
	Cost of design changes		D
Other	Space requirements		NC
	Number of product units		I
	Clients services		I
	Personnel working condition/environment		I
	Flow of information		I

Note: NC – no change; I – improvement; D – deterioration.

The total cost value for this new layout is calculated as $ 110 196 which is less than the initial layout cost. Hence, the new layout based on the safety and cost factors is an improvement to the current layout of the kitchen.

It should be mentioned that this new layout is just one example of the possible improved layout designs for our case study. Iterating the steps of the proposed model can lead to other layout designs.

5. Discussion

The layout design changes of the kitchen at the hospital were proposed to ultimately replace the old facility, designed in 1907. The new layout is aimed to be able to serve more clients (patients) while supporting additional services such as room services. The new layout design that is proposed in this paper not only covers these purposes but also suggest a layout which improves the OHS for the personnel and their working environment. A comparison between the new layout and the old one is presented in Table 7. Current layout of the kitchen is compared to the proposed layout design in regards to OHS issues, cost and other important factors.

Concerning the four safety scenarios, changes in the new layout design has improved the OHS issues for Scenario 1 by changing the location of the ‘dish washing area’ and ‘offices’ (Scenario 1). In addition, locating the ‘dish washing area’ further from ‘cold storage 1 or 2’ departments has improved the OHS issues for Scenario 3. Changes in locations of departments did not have any significant OHS difference for the other two scenarios. However, re-applying the methodology could result in further safety improvements.

The total cost of developing the layout decreases for the proposed layout design comparing to the old one. However, considering that the kitchen already exist, re-designing of its layout require cost of design changes.

The total available space is considered to be fixed (13,000 ft^2) for developing the new layout design; while the proposed layout improved the possibility of preparing more food (meal request) as well as offering additional services to the patients and their visitors.

Furthermore, the working condition and environment is enriched for the kitchen personnel in regards to the OHS issues, whereas the human factor risks are decreased in the new layout design. Besides, the location of ‘offices’ and ‘warehouse’ departments are enough close to each other to improve the communications between these two departments.

Therefore, the new layout design, which concurrently considers OHS and cost factors, is an improvement to the current layout of the kitchen.

6. Conclusion

Facilities layout design is an important industrial issue as it directly and indirectly results in higher efficiency of the system. A practical layout design should meet multiple objectives rather than a single one (e.g. material handling cost); multiple objectives models for layout design, especially qualitative objectives such as safety, require further research. In an effort to improve the facility layout planning models, this paper investigated how facility planning models and risk estimation tools can be improved and integrated in order to provide a more robust method that can better meet productivity and safety requirements. A case study involving a kitchen of a hospital is presented.

Acknowledgements

We would like to thank NSERC for its financial support.

References

Aksorn, T., and B. H. W. Hadikusumo. 2008. “Critical Success Factors Influencing Safety Program Performance in Thai Construction Projects.” *Safety Science* 46 (4): 709–727.

Behm, M. 2005. “Linking Construction Fatalities to the Design for Construction Safety Concept.” *Safety Science* 43 (8): 589–611.

Benjaoran, V., and S. Bhokha. 2010. “An Integrated Safety Management with Construction Management Using 4D CAD Model.” *Safety Science* 48 (3): 395–403.

Broberg, O. 2011. “The Workspace Design Approach: How Users and OHS Consultants Can Transform Design Scripts.” Paper presented at the Nordic Ergonomics Society Annual Conference: Ergonomics is a Lifestyle, Oulu, Finland.

De Alvarenga, A. G., and F. J. Negreiros-Gomes. 2000. “Metaheuristic Methods for a Class of the Facility Layout Problem.” *Journal of Intelligent Manufacturing* 11 (4): 421–430.

De Oliveira Matias, J. C., and D. A. Coelho. 2002. “The Integration of the Standards Systems of Quality Management, Environmental Management and Occupational Health and Safety Management.” *International Journal of Production Research* 40 (15): 3857–3866.

Hadke, A. B., and M. M. Gupta. 2013. “An Ergonomic Assessment of Workers at Nuclear Power Plant (NPCIL).” *International Journal Technology* 3 (1): 42–49.

Hall-Andersen, L. B., and O. Broberg. 2013. “Integrating Ergonomics into Engineering Design: The Role of Objects.” *Applied Ergonomics* 1–8.

Ho, W., X. Xu, and P. K. Dey. 2010. “Multi-criteria Decision Making Approaches for Supplier Evaluation and Selection: A Literature Review.” *European Journal of Operational Research* 202 (1): 16–24.

ILO. 2012. “Your Health and Safety at Work: Introduction to Occupational Health and Safety.” Accessed February 17. http://actrav.itcilo.org/actrav-english/telearn/osh/intro/introduc.htm

Islier, A. A. 1998. “A Genetic Algorithm Approach for Multiple Criteria Facility Layout Design.” *International Journal of Production Research* 36 (6): 1549–1569.

Karray, F., E. Zaneldin, T. Hegazy, A. H. M. Shabeeb, and E. Elbeltagi. 2000. “Tools of Soft Computing as Applied to the Problem of Facilities Layout Planning.” *IEEE Transactions on Fuzzy Systems* 8 (4): 367–379.

Kleban, S. D., G. F. Luger, and R. D. Watkins. 1996. “Expert System Support for Environmental Assessment of Manufacturing Products and Facilities.” *Journal of Intelligent Manufacturing* 7 (1): 39–53.

Kochhar, J. S. 1999. “Facility Layout Design in a Changing Environment.” *International Journal of Production Research* 37 (11): 2429–2446.

Lefrancois, P., and B. Montreuil. 1994. “An Organism-oriented Modeling Approach to Support the Analysis and Design of Intelligent Manufacturing Systems.” *Journal of Intelligent Manufacturing* 5 (2): 121–142.

Melzner, J., S. Zhang, J. Teizer, and H. J. Bargstädt. 2013. “A Case Study on Automated Safety Compliance Checking to Assist Fall Protection Design and Planning in Building Information Models.” *Construction Management and Economics* 31 (6): 661–674.

Meswani, H. R. 2008. “Safety and Occupational Health: Challenges and Opportunities in Emerging Economies.” *Indian Journal of Occupational and Environmental Medicine* 12 (1): 3–9.

Moatari-Kazerouni, A., Y. Chinniah, and B. Agard. 2014a. “A Proposed Occupational Health and Safety Risk Estimation Tool for Manufacturing Systems.” *International Journal of Production Research* (ahead-of-print). 1–17. doi:10.1080/00207543.2014.942005.

Moatari-Kazerouni, A., Y. Chinniah, and B. Agard. 2014b. “Integrating Occupational Health and Safety in Facility Layout Planning, Part I: Methodology.” *International Journal of Production Research*. doi: 10.1080/00207543.2014.970712.

Muther, R. 1973. *Systematic Layout Planning*. 2nd ed. Boston, MA: Cahners Books.

Neumann, W. P., S. Kihlberg, P. Medbo, S. E. Mathiassen, and J. Winkel. 2002. “A Case Study Evaluating the Ergonomic and Productivity Impacts of Partial Automation Strategies in the Electronics Industry.” *International Journal of Production Research* 40 (16): 4059–4075.

Saari, J., S. Bedard, V. Dufort, and J. Hryniewiecki. 1993. “How Companies Respond to New Safety Regulations: A Canadian Investigation.” *International Labour Review* 132: 65–74.

Shikdar, A. A., and S. A. Al-Araimi. 2001. “Ergonomic Conditions in Small Manufacturing Industries.” *Science and Technology* 6: 61–70.

Shikdar, A. A., S. Al-Araimi, and B. Omurtag. 2002. “Development of a Software Package for Ergonomic Assessment of Manufacturing Industry.” *Computers & Industrial Engineering* 43 (3): 485–493.

Shikdar, A. A., and N. M. Sawaqed. 2003. “Worker Productivity, and Occupational Health and Safety Issues in Selected Industries.” *Computers & Industrial Engineering* 45 (4): 563–572.

Silvestri, A., F. De Felice, and A. Petrillo. 2012. “Multi-criteria Risk Analysis to Improve Safety in Manufacturing Systems.” *International Journal of Production Research* 50 (17): 4806–4821.

Tam, C. M., S. X. Zeng, and Z. M. Deng. 2004. “Identifying Elements of Poor Construction Safety Management in China.” *Safety Science* 42 (7): 569–586.

Tompkins, J. A., J. A. White, Y. A. Bozer, and J. M. A. Tanchoco. 2010. *Facilities Planning*. 4th ed. New York: Wiley, 854 p.