Alternative Global Layered Cellular Designs for a Blood Sugar Strip Manufacturer

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***Abstract*— This paper discusses alternative supply chain design strategies for a global blood sugar strip manufacturing company. Two main alternatives considered are: 1) Single location manufacturing plant to meet world demand located in China; 2) three manufacturing plants located in three regions to meet world demand, China for Asian market, Ireland for European market and Puerto Rico for North American market. Manufacturing plants are designed considering layered cellular design approach under stochastic demand. This approach allows three types of cells to be formed: 1) dedicated cells for families, 2) shared cells, cells to be shared by two families, 3) remainder cells, cells to be used by three or more families. The main focus of this paper is to compare both alternatives by considering labor costs, machine investment costs and transportation costs. We will also discuss detailed operational control issues in one of the plants and discuss simulation results to validate the results obtained through layered design methodology. The results show that single manufacturing plant option is a more economical option even though related transportations costs are substantial but labor costs are drastically reduced if products are built in China.**

***Keywords*—** *Supply Chain Design, Manufacturing System, Heuristic Algorithm, Simulation, Layered Cellular Design*

1 Introduction

This research focuses on designing a manufacturing system for a global blood sugar strip manufacturer. Three manufacturing facilities are assumed to meet the demand of three regions. Using cellular manufacturing concepts, number and type of manufacturing cells are determined for each manufacturing facility considering demand data. Later, this supply chain strategy is compared with the one where all manufacturing is done in a single facility. A probabilistic method is used first to do system design and then the theoretical results are verified using simulation analysis. Finally, cost analysis is conducted to compare machine cost, labor cost and transportation cost between two alternatives.

1.1 Classification of Manufacturing System

The type of a manufacturing system mostly depends on the layout of the manufacturing system. Manufacturing system is classified into four categories based on the layout which is shown in Figure 1: process layout, fixed layout, cellular layout and product layout. Fixed Layout deals with heavy products, which stay in the same position and workers, machines and equipment are brought to the product [1]. Product Layout is used when product volume is high and product variety is low. Product layout is usually very efficient but inflexible system. Process Layout is used for low product volume systems with a high product variety [1]. These systems are very flexible but not very efficient. Cellular Layout is more flexible than Product Layout. It suits for high product variety with low to moderate demand [1].

Cellular Manufacturing is based on the grouping of similar products with respect to common processes into one cell. In the real world, many uncertainties exist in the system such as demand uncertainty, supply uncertainty and processing uncertainty. These uncertainties have been discussed in related research. The uncertainties of product demand and processing times are considered [1]. By probabilistic market demand calculation, the part-family assignment is achieved [1]. Then, low utilized cells are grouped to increase the utilization of the system.

1.2 Supply Chain

Supply chain is the network connecting between suppliers, manufacturers, distribution centers and customers [2]. Many supply chain models were discussed [3]. Among them, globally concentrated production model, host market production model and regional/global product specialization model are mentioned. Specifically, each of the geographic regions covers its own demand of that geographic region in the host market production model as shown in Figure 2. On the other hand, one manufacturing facility produces all the demand from all over the world in the globally concentrated production model as shown in Figure 3. In this study, these two models are discussed.

Ref. [19] discussed dual demand management in a windows Supply Chain company, namely, make-to-engineer and make-to-order.

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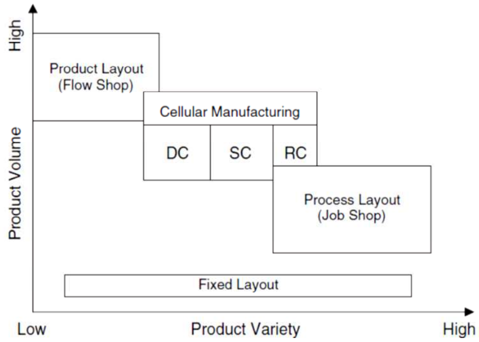

Figure 1. Four types of manufacturing layout [1]

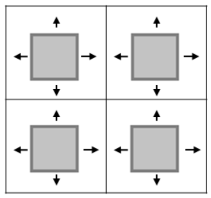

Figure 2. Host market production model [3]

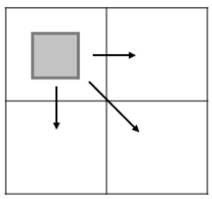

Figure 3. Globally concentrated production model

2 Literature Review

Literature regarding to global supply chain and manufacturing systems is summarized in this section.

2.1 Global Location Strategy Models

Supply chain model includes three logistical drivers and three cross functional drivers [4]. Three logical drivers are facilities, inventory and transportation and three cross functional drivers are information, sourcing and pricing. Many factors affected a sophisticated network of multinational manufacturing facilities [5]. This integrated network included independent and integrated plant choices. Besides considering facility selection, a facility location model was developed to study the location decision of high technology firms [6]. The model identified the international manufacturing facility location based on domestic and potential international production markets, which allowed production to be transferred from domestic manufacturing facilities to foreign ones. A two-phase multi-screening approach including production capacity was developed for incorporating uncertainty about exchange rates and exchange rate risk in an international production and sourcing model [7]. National market was improved into the global supply chain market by considering connection among global markets [8]. In order to solve the global manufacturing problems, an integrative mathematical model was developed to connect global manufacturing and marketing [8].

2.2 Cellular Manufacturing Design / Group Technology

Group Technology (GT) was introduced to improve productivity in the Cellular Manufacturing System (CMS) [9]. Not many works in the literature were used with fuzzy concepts to deal with multi-objective framework in the process [10]. A supplementary procedure was proposed to solve the limitation of Adaptive Resonance Theory (ART) [11]. They mentioned that the performance of ART depended on the initial matrix of bottleneck process. Moreover, a new mathematical model based on cell utilization was conducted [12]. A mixed integer non-linear model was analysed for CMS [13]. In their paper, the proposed model was an integrated approach to combine production planning and system reconfiguration. This CMS model was a new model, which includes sequence, duplicate machines, capacity of machines and lot splitting.

The literature reviews discussed so far included the deterministic CMS problem. However, cellular manufacturing is difficult to design in the real world due to uncertainty of the manufacturing process. In order to deal with the uncertainty of product demand along with processing time, another research is proposed [1]. A heuristic methodology was conducted to distinguish cell types in the CMS - Dedicated Cell (DC), Shared Cell (SC) and Remainder Cell (RC). The product family configuration and cell allocation are accomplished by using mathematical modeling. The designed manufacturing system turned to successfully solve the uncertainty of product demand and processing time through simulation method. The methodology is implemented in the current research for the purpose of designing the manufacturing system given the market demand, part-family formations, and the operations required to process the products.

Egilmez, Suer and Ozguner [20] proposed a stochastic cellular manufacturing system design considering hybrid similarity coefficient.

3 Problem Definition

In this research, a blood glucose test strip manufacturing system is considered to study the alternative supply chain design approaches, namely independent facilities per region vs. single manufacturing facility. The procedure used to decide shared manufacturing cells is explained in Section 3.1. Subsequently, comparison between independent facilities and single manufacturing facility is conducted in Section 3.2. Customers from three regions are considered to be the most influential consumer force – Europe, Asia and

North America. Three manufacturing facilities are assumed to produce the products – Ireland, China and Puerto Rico. The production data and manufacturing processes are discussed in [14]. Most of the demand data are converted into common units by considering market share, revenue, and product price [15].

3.1 Manufacturing Cell Design

In most manufacturing systems, different products require to be processed on different machines. Due to high product variety, products are grouped into several families based on their similarity. Table 1 shows an example of product-machine incidence matrix. In this table, "1" in row i and column j indicates that product i needs to be produced on machine j. For example, Product 1 (P1) is processed on Machine 1 (M1), Machine 2 (M2) and Machine 3 (M3). One can observe that products with similar manufacturing processes are grouped together. Table 2 shows families and cells they are assigned to in cellular manufacturing.

Table 1. An example of product-machine incidence matrix

	M1	M2	M3	M4	M5
P1	1	1	1		
P2	1		1		
P3		1	1		
P4				1	1
P5				1	1
P6	1		1		1
P7	1				1

Table 2. Product families and cells

Family	Products	Cell	Machines in the Cell
F1	P1, P2, P3	Cell1	M1, M2, M3
F2	P4,P5	Cell2	M4, M5
F3	P6,P7	Cell3	M1, M3, M5

However, in real life manufacturing systems, some product families may have quite high demand, which means they cannot be produced in one cell. Table 3 shows this multiple cell production system. For example, due to high demand, product families 1, 2 and 3 may need 2, 3 and 2 cells, respectively.

Yet another possibility is that demand values for product families follow a probabilistic distribution. In some cases, expected utilization for some cells of families may be low. As a result, several product families may be expected to share one cell. A Dedicated Cell (DC) deals with one product family. A Shared Cell (SC) operates two product families, which have relatively similar operations. A Remainder Cell (RC) handles more than two product families. Both Shared Cells and Remainder Cells usually handle product families that have medium or low expected utilization values for some of its cells. Table 4 shows the cell sharing between three product families. For example, Cell 1 (C1) is Dedicated Cell for Product Family 1(F1). C2 is also Dedicated Cell for F2. C3 is a Remainder Cell to be shared by F1, F2 and F3. Finally, C4 is a Shared Cell between F2 and F3.

Table 3. Family vs. Multiple cells due to high demand

	C1	C2	C3	C4	C5	C6	C7
F1	1	1					
F2			1	1	1		
F3						1	1

Table 4. Layered cellular design due to stochastic demand

	C1	C2	C3	C4
F1	1		1	
F2		1	1	1
F3			1	1
	(DC)	(DC)	(RC)	(SC)

3.2 Alternative Supply Chain Designs

In this section, two alternative supply chain design strategies are discussed. Strategy 1 discusses the independent supply chain design which means the manufacturing facilities produce products independently in each region, namely North America, Asia and Europe by using three manufacturing facilities located in Puerto Rico, China and Ireland, respectively. Strategy 2 is the single location manufacturing system in which all of the products are produced in one location.

3.2.1 Strategy 1: Independent Supply Chain Design

In this strategy, each region produces many types of products to meet the demand of its own demand. Products are produced independently in different facilities, which lead to no transportation and information sharing between different regions. Figure 4 shows that the blood sugar strips are produced in three manufacturing facilities – China, Ireland and Puerto Rico.

3.2.2 Strategy 2: Single Manufacturing Facility Design

In this strategy, one single manufacturing facility produces all the products. The location analysis of this facility is not within the scope of this paper.

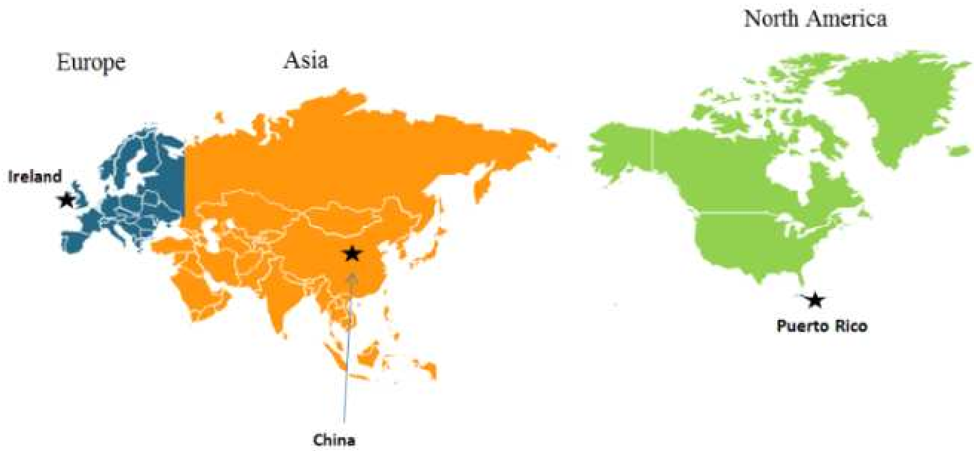

Figure 4. Independent manufacturing systems

4 Methodology Used

In each manufacturing facility, there are both fabrication and packaging cells. Products are divided into five product families based on product family similarity in manufacturing processes. In this study, we assume that product families have been already identified.

Two alternative models will be discussed in Section 4.1 and Section 4.2. An independent supply chain model is presented in Section 4.1. Cell utilizations are calculated by using cell capacity, product demand, etc. (Section 4.1.3). Each cell capacity is assumed 2000 hours annually. Cell utilization captures the usage of each cell. By considering the cell utilization, different cells can be combined into one as long as capacity is available (Section 4.1.4). Single manufacturing model is discussed in Section 4.2. Then simulation is implemented to realize the model together with the optimal result of the research (Section 4.3). In Figure 5, the general methodology is presented.

4.1 Independent Manufacturing Facilities

4.1.1 Mean Capacity Requirements and Standard Deviation

Historical demand values of four companies – Roche, LifeScan, Bayer and Abbott from 2002 to 2010 are used to calculate the 2011 demand [15].

In this research, it is assumed that demand is normally distributed. Standard Deviation (σ) values for each product family are generated as a percentage of the mean demand (20% - 25%). It is assumed that if Mean Demand is high, low percentage will be assigned to minimize the uncertainty among data. Most of the mean demands by family in all markets are from (2013), which is shown in Table 5. Also, Standard Deviations (σ) in three regions are given in Table 5.

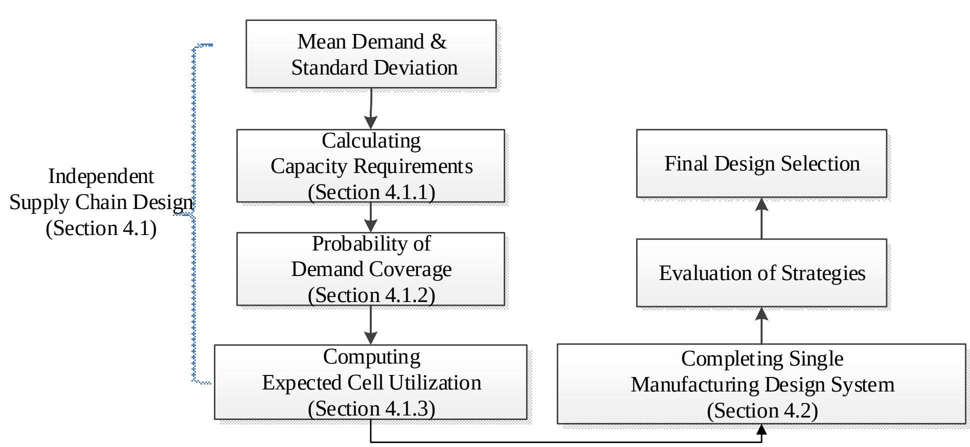

Figure 5. Methodology flowchart

Table 5(a). Mean demand and standard deviation by family – China region

	China		
F	Mean	%	STDEV
1	1,422,286	25	355,571
2	7,098,188	24	1,703,565
3	6,711,423	24	1,610,741
4	24,313,26	21	5,105,784
5	3,137,454	25	784,363

Table 5(b). Mean demand and standard deviation by family – Ireland region

	Ireland		
F	Mean	%	STDEV
1	1,422,9	25	355,731
2	7,101,3	24	1,704,330
3	6,714,4	24	1,611,465
4	22,000,	21	4,620,000
5	3,138,8	25	784,715

Table 5(c). Mean demand and standard deviation by family – Puerto Rico region

	PR		
F	Mean	%	STDEV
1	1,337,0	25	334,271
2	6,672,9	24	1,601,516
3	6,309,3	24	1,514,253
4	22,856,	21	4,799,933
5	2,949,5	25	737,377

Having mean demand values and standard deviations, the mean capacity requirements by product family are calculated by using Equation 1 [16]. Bottleneck Processing Time is defined by the bottleneck machine as the longest processing time in the cell.

$$MCR_F = Mean_{Demand} * \frac{BPT}{60}(hr) \quad (1)$$

For example, Mean Capacity Requirements for Product Family 1 in the manufacturing system of China region is decided by Mean Demand by Product Family 1 in China region which is 1,422,286. BPT (Bottleneck Processing Time) is 1/80 = 0.0125 min in the China region. The results of Mean Capacity Requirements and standard deviation for different regions are shown in Table 6.

$$MCR_{F1} = 1{,}422{,}286 * \frac{0.0125}{60} = 296$$

$$STDEV_{CapacityF1} = \sqrt{355{,}571^2 * \frac{0.0125^2}{3600}} = 74$$

Table 6(a). Mean capacity requirements and standard deviation – China region

China		
Family	**MCR**	**STDEV**
1	296	74
2	1479	355
3	1868	448
4	5065	1064
5	654	163

Table 6(b). Mean capacity requirements and standard deviation – Ireland region

Ireland		
Family	**MCR**	**STDEV**
1	296	74
2	1479	355
3	1869	449
4	4583	963
5	654	163

Table 6(c). Mean capacity requirements and standard deviation – Puerto Rico region

PR		
Family	**MCR**	**STDEV**
1	279	70
2	1390	334
3	1756	421
4	4762	1000
5	614	154

4.1.2 Demand Coverage Probabilities

The demand coverage probability shows the probability that a given number of cells will meet the demand. In this paper, the number of cells to process the particular family of products is unknown. At the same time, demand is assumed to follow the normal distribution. The annual labor time in one cell is 2000 hrs. Mean Capacity Requirement (MCR) is calculated in Section 4.1.1. Demand Coverage Probability (DCP) for a family and cell combination is calculated by Equation 2 [16].

For Cell 1 of Product Family 1 for China market, Demand Coverage Probability for a given number of cells is decided by Mean Capacity Requirement and Standard Deviation. Mean Capacity Requirement for Product Family 1 for China region is 296 which is shown in Table 6. Standard Deviation for Product Family 1 for China region is 74, which is also shown in Table 6. Based on these values, the Demand Coverage Probability for the first cell is 99.99%. In other words, only one cell is sufficient to cover demand almost fully for Family 1.

$$DCP_{FC} = Normsdist\left(\frac{2000 * CellNo. - MCR_F}{STDEV_{Capacity}}\right) \quad (2)$$

All the results of Demand Coverage Probabilities for different regions are shown in Table 7. For family 2 in China facility, one cell will cover demand 93% of the time. By adding a second cell, the Demand Coverage Probability jumps to 99.99%.

$$DCP_{F1C1} = Normsdist\left(\frac{2000 * 1. - 296}{74}\right) = 1$$

All the results of Demand Coverage Probabilities for different regions are shown in Table 7. For family 2 in China facility, one cell will cover demand 93% of the time. By adding a second cell, the Demand Coverage Probability jumps to 99.99%.

Table 7(a): Demand coverage probabilities- China

Family \ Cell	1	2	3	4	5
	China				
1	1.00				
2	0.93	1.00			
3	0.62	1.00			
4	0.001	0.16	0.81	0.99	1.00
5	1.00				

Table 7(b): Demand coverage probabilities-Ireland

Family \ Cell	1	2	3	4	5
	Ireland				
1	1.00				
2	0.93	1.00			
3	0.61	1.00			
4	0.004	0.37	0.93	0.99	1.00
5	1.00				

Table 7(c): Demand coverage probabilities-PR

Family \ Cell	1	2	3	4	5
	PR				
1	1.00				
2	0.97	1.00			
3	0.72	1.00			
4	0.001	0.22	0.89	0.99	1.00
5	1.00				

4.1.3 Expected Cell Utilization Calculation

Expected Cell Utilization is determined by using Demand Coverage Probability, Mean and Standard Deviation from Equation 3 to Equation 6 [17].

$$E(C = X) = P(CR > X) * PU_1 + P(X - 1 \leq CR \leq X) * PU_2 + P(CR < X - 1) * PU_3 \quad (3)$$

Where

E(C=X) Expected cell utilization for the Xth cell in a product family
P(CR>X) Probability that the number of cells required (CR) > X
PU1 Percentage utilization of the Xth cell when CR > X, PU1 =1.0
P(X-1≤CR≤X) Probability that CR between X-1 and X
PU2 Percentage utilization of Xth cell when CR between X-1 and X
P(CR<X-1) Probability that CR < X-1
PU3 Percentage utilization of Xth cell when CR < X-1, PU3 = 0.0
PU2 is solved by Equation 4.

$$PU_2 = \int_{2000(X-1)}^{2000X} \frac{y * f(y)}{2000 * A} dy - (X - 1) \quad (4)$$

Where

y Variable represents CR
f(y) Probability density formation for CR
A Probability that CR between X-1 and X

f(y) and A are calculated by Equations 5 and 6, respectively.

$$f(y) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2 \frac{1}{2\sigma^2}} \quad (5)$$

$$A = P(X - 1 \leq CR \leq X) \quad (6)$$

For example, Expected Cell Utilization of Product Family 1 for China region is decided by probability that the number of cell required is greater than than 1, Percentage utilization of the 1st cell when CR > 1, Probability that CR between 0 and 1 and Percentage utilization of 1st cell when CR between 0 and 1.

$$E(C = 1) = P(CR > 2000) * PU_1 + P(0 \leq CR \leq 2000) * PU_2 + P(CR < 0) * PU_3 = 0 * 1 + 1 * PU_2 = PU_2$$
$$= \int_0^{2000} \frac{y}{2000 * 1} * \frac{1}{74 * \sqrt{2\pi}} e^{-(y-296)^2 * \frac{1}{2 * 74^2}} dy = 0.1480$$

All of the results of Expected Cell Utilizations for different regions are shown in Table 8.

Table 8(a). Expected cell utilization values-China

China					
Family \ Cell	1	2	3	4	5
1	0.15	0.00			
2	0.73	0.01	0.00		
3	0.87	0.06	0.00		
4	1.00	0.96	0.52	0.06	0.00
5	0.33	0.00			

Table 8(b). Expected cell utilization values-Ireland

Ireland					
Family \ Cell	1	2	3	4	5
1	0.15	0.00			
2	0.73	0.01	0.00		
3	0.87	0.06	0.00		
4	1.00	0.92	0.36	0.02	0.00
5	0.33	0.00			

Table 8(c). Expected cell utilization values-PR

PR					
Family \ Cell	1	2	3	4	5
1	0.14	0.00			
2	0.69	0.00	0.00		
3	0.84	0.04	0.00		
4	1.00	0.94	0.42	0.03	0.00
5	0.31	0.00			

4.1.4 Heuristic Algorithm for Layered Cellular Design

Having determined Expected Cell Utilization values, Dedicated Cells (DC), Shared Cells (SC), and Remainder Cells (RC) are identified. The heuristic algorithm is used for identifying cell [1]. When all the Expected Cell Utilization values in three regions are calculated in Section 4.1.3, manufacturing cell types is determined by a heuristic algorithm. Expected Cell Utilizations are sorted in decreasing order with the highest Expected Cell Utilization considered. If the Expected Cell Utilization is 100%, this cell is considered to be a Dedicated Cell (DC). If the Expected Cell Utilization is larger than 50%, a cell will be allocated to a product family. Then other similar product families are allocated to the cell to make the cell utilization close to 100% by considering similarities among families. These cells are named Shared Cells (SC) if they process only two product families. If the Expected Cell Utilization is smaller than 50% and cannot be merged with existing cells, these cells will be grouped together to form a Remainder Cell (RC). Typically, Remainder Cells will process three or more product families. The threshold value is the lowest acceptable similarity coefficient that allows two families to be grouped in a cell. The Similarity Threshold is set to 77% in this research.

Table 9. Similarity coefficients between product families

Family	1	2	3	4	5
1		1.00	0.89	0.78	0.70
2	1.00		0.89	0.78	0.70
3	0.89	0.89		0.70	0.80
4	0.78	0.78	0.70		0.89
5	0.70	0.70	0.80	0.89	

For example, when sorting the ECU for China region, the highest ECU is 100% of Product Family 4 in Cell 1. Then Product family 4 is allocated to Cell 1. When the second cell with 0.96% utilization considered, it is allocated to a new cell – Cell 2. Table 9 is used to search the other similar Product Families with Product Family 4. From Table 9, Families 1, 2 and 5 are considered to share a cell with Product Family 4. Since merging this cell with Family 1 and Family 5 will exceed 100% utilization, the only option is to merge Cell 2 (1% utilization) of Family 2 with Family 4. In China case, there are two Dedicated Cells, two Shared Cells and one Remainder Cell. Similar distributions occur in all cases.

Table 10(a). Cells China region

China					
Family \ Cell	1	2	3	4	5
1				0.15	
2		0.01		0.73	
3			0.87	0.06	
4	1.00	0.96		0.06	0.52
5					0.33
	DC	SC	DC	RC	SC

Table 10(b). Cells Ireland region

Ireland					
Family \ Cell	1	2	3	4	5
1				0.15	
2		0.01		0.73	
3			0.87	0.06	
4	1.00	0.92		0.02	0.36
5					0.33
	DC	SC	DC	RC	SC

Table 10(c). Cells PR region

PR					
Family \ Cell	1	2	3	4	5
1				0.14	
2				0.69	
3			0.84	0.04	
4	1.00	0.94		0.03	0.42
5					0.31
	DC	DC	DC	RC	SC

4.2 Single Manufacturing Facility

In this section, all the processes are similar to Section 4.1. Total mean demand values are presented in Table 11. Standard deviation values are calculated based on standard deviation values from different regions. Table 12 shows Cell Type for single manufacturing design after heuristic algorithm.

Table 11. Mean demand and standard deviation for single system

Family	$\text{Mean}_{\text{Demand}}$	$\text{STDEV}_{\text{Demand}}$
1	4,182,298	603,914
2	20,872,551	2,893,394
3	19,735,250	2,735,739
4	69,170,087	8,393,616
5	9,225,828	1,332,189

Table 12. Cell type for single manufacturing design

Cell / Family	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														0.44
2						1.00				0.95			0.23	
3					1.00			1.00			0.06		0.69	
4	1.00	1.00	1.00	1.00			1.0		0.97	0.01		0.78	0.08	0.37
5											0.92	0.04		
	DC	DC	DC	DC	DC	DC	DC	DC	DC	SC	SC	SC	RC	SC

4.3 Simulation Experiment

Simulation models can be developed for manufacturing systems in each region. In this section, a simulation model for China region is developed to compare the results with the Expected Cell Utilization results reported in Section 4.1.3. The total running time is assumed to be 2000 hours in a year. Before assigning vials into cells, the vials are held until they are grouped into three units. Lot sizing is important when considering setup time. After decision modules, vials are assigned to different cells. In each cell, vials have several operations processed on different machines. The number of machines and processing times on each machine are included based on different vial types. During the simulation, queue sizes that control the utilization of different cells are identified to reach theoretical cell utilization values as shown in Table 13 and illustrated in Figure 6 for Family 4. A queue size 100 shows that product family 4 products join queue of C1 first. If the current queue is 100, then they are sent to C2. Similarly, if current queue in C2 is 100, then they are transferred to C5 and so on.

Table 13. Queue size in china region

	Cell Utilizations					Queue Size				
C / F	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1				0.15						
2		0.01		0.73					1000	
3			0.87	0.06				100		
4	1.00	0.96		0.06	0.52	100	100			100
5					0.33					

Cell utilization is also an important index in the manufacturing system. Table 14 shows the comparison of average cell utilizations in the simulation model and expected cell utilizations in Section 4.1.3. The maximum deviation is around 5.0%, which indicates that the simulation model realizes results reasonably well.

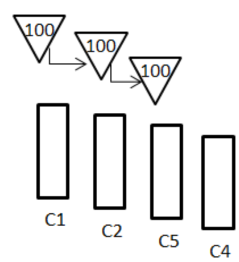

Figure 6. Queue size arrangement in family 4

Table 14. Simulation cell utilization vs. expected cell utilization in China region

Cell	Simulation	Expected Cell Utilization	Deviation (%)
Cell1	1.0000	0.9997	0.03
Cell2	0.9655	0.9611	0.5
Cell3	0.9190	0.8737	5.0
Cell4	0.9787	0.9971	1.8
Cell5	0.8825	0.8489	4.0

Several attempts are made to establish queue sizes. Table 15 shows another set of queue size values and corresponding utilization results.

Table 15. Another queue size with comparison of cell utilizations in china region [18]

Cell	1	2	3	4	5	Simulation	Expected Cell Utilization	Deviation (%)
F1						1.0000	0.9997	0.03
F2				2000		1.0000	0.9611	4.0
F3			500			0.9145	0.8737	4.7
F4	100	800			2000	0.9136	0.9971	8.4
F5						0.9268	0.8489	9.2

4.4 Cost Analysis

In this section, labor cost, machine cost and transportation cost are discussed. Labor cost and machine cost are be included in both of the alternatives while transportation cost is only considered discussed in single manufacturing facility design. Facility is considered to be placed in China when single manufacturing facility strategy happens.

4.4.1 Labor Cost

The number of workers in each product family and hourly labor cost are calculated [15]. Number of labor in each facility for independent supply chain strategy and single manufacturing strategy are shown in Table 16 and Table 17. There are 15 cells in the independent supply chain strategy and 14 cells in the single manufacturing strategy.

Table 16. Number of labor in each facility for independent supply chain strategy [18]

Cell	Op1	2	3	4	5	6	7	8	9	Total
1	1	4	1	1	1	4	1	1	0	14
2	1	4	1	1	1	4	1	1	0	14
3	1	4	1	1	1	4	1	1	3	17
4	1	4	1	1	1	4	1	1	3	17
5	1	4	1	1	1	4	1	1	6	20

Number of workers and labor costs are shown in Table 18. Since there are fewer cells in the single manufacturing strategy and the hourly labor cost is much lower in China, labor cost for single manufacturing strategy is much lower than independent supply chain strategy.

Table 17. Number of labor for single manufacturing strategy [18]

Cell	Op1	2	3	4	5	6	7	8	9	Total
1	1	4	1	1	1	4	1	1	0	14
2	1	4	1	1	1	4	1	1	0	14
3	1	4	1	1	1	4	1	1	0	14
4	1	4	1	1	1	4	1	1	0	14
5	1	4	1	1	1	4	1	1	3	17
6	1	4	1	1	1	4	1	1	0	14
7	1	4	1	1	1	4	1	1	0	14
8	1	4	1	1	1	4	1	1	3	17
9	1	4	1	1	1	4	1	1	0	14
10	1	4	1	1	1	4	1	1	0	14
11	1	4	1	1	1	4	1	1	6	20
12	1	4	1	1	1	4	1	1	6	20
13	1	4	1	1	1	4	1	1	3	17
14	1	4	1	1	1	4	1	1	0	14

Table 18. Number of workers and labor cost [18]

Labor	Independent Supply Chain Strategy		Single Manufacturing Strategy (If in China)	
	Number	Cost	No.	Cost
China	82	$319,800	217	$846,300
Ireland	82	$3,434,160		-
PR	82	$3,524,360		-
Total	246	$7,278,320	217	$846,300

4.4.2 Machine Cost

Similar to labor cost, the number of machines in each product family and hourly machine cost are also calculated [15]. Number of machines in each facility for independent supply chain strategy and single manufacturing strategy are shown in Table 19 and Table 20. Number of machines and machine costs are shown in Table 21. Since fewer cells are needed in single manufacturing strategy, single manufacturing strategy uses less machine cost.

Table 19. Number of machines for independent supply chain strategy [18]

Cell	Op1	2	3	4	5	6	7	8	9	Total
1	1	4	1	1	1	4	1	1	0	14
2	1	4	1	1	1	4	1	1	0	14
3	1	4	1	1	1	0	1	1	0	10
4	1	4	1	1	1	4	1	1	0	14
5	1	4	1	1	1	4	1	1	0	14

Table 20. Number of machines for single manufacturing strategy [18]

Cell	Op1	2	3	4	5	6	7	8	9	Total
1	1	4	1	1	1	4	1	1	0	14
2	1	4	1	1	1	4	1	1	0	14
3	1	4	1	1	1	4	1	1	0	14
4	1	4	1	1	1	4	1	1	0	14
5	1	4	1	1	1	0	1	1	0	10
6	1	4	1	1	1	0	1	1	0	10
7	1	4	1	1	1	4	1	1	0	14
8	1	4	1	1	1	0	1	1	0	10
9	1	4	1	1	1	4	1	1	0	14
10	1	4	1	1	1	4	1	1	0	14
11	1	4	1	1	1	4	1	1	0	14
12	1	4	1	1	1	4	1	1	0	14
13	1	4	1	1	1	4	1	1	0	14
14	1	4	1	1	1	4	1	1	0	14

Table 21. Number of machines for single manufacturing strategy [18]

Machine	Independent Supply Chain Strategy		Single Manufacturing Strategy (If in China)	
	No.	Cost	No.	Cost
China	66	$4,030,000	184	$11,220,000
Ireland	66	$4,030,000	-	-
PR	66	$4,030,000	-	-
Total	198	$12,090,000	184	$11,220,000

4.4.3 Transportation Cost

Transportation cost only exists in the single manufacturing facility strategy since product families need to be transported to other regions. In this research, maritime transportation is considered as the only transportation method. Table 22 shows the transportation cost for single manufacturing facility strategy.

Table 22. Transportation cost for single manufacturing strategy [18]

	China - Ireland	China - PR
Total Number of Units	40,377,603	40,125,799
Capacity/Container	172000	172000
Number of Container	235	234
Unit Container Cost	$4,914.54	$2,629.48
Transportation Cost	$1,154,916.90	$615,297.15
Total Transportation Cost	$1,770,214.05	

5 Conclusion

The comparison between the two designs is presented in Table 23. It shows a single manufacturing facility can produce product families more efficiently, which means cells have higher utilization in single manufacturing system compared to multiple independent plants. Single facility could be located in Ireland or in Puerto Rico or in China. In this study we chose China location due to lower labor rates in China. This paper differs from many other works in the literature since it adapts layered cellular design in the context of supply chain analysis.

Table 23. Comparison between independent model and single manufacturing system

	Independent	**Single**
# of DCs	7	9
# of SCs	5	4
# of RCs	3	1
# of total cells	15	14
# of Cell Util over 90%	9	12

When labor cost, machine cost and transportation cost are considered, the total cost for single manufacturing facility strategy is much lower as shown in Table 24.

Table 24. Total Cost for Two Strategies [18]

Cost	Independent Supply Chain Design	Single Manufacturing Strategy
Labor	$7,278,320.00	$846,300.00
Machine	$12,090,000.00	$11,220,000.00
Transportation	-	$1,770,214.05
Total	$19,368,320.00	$13,836,514.05

6 Future Work

In this research, only one transportation method is considered, which is maritime transportation. In the real world, transporting by air, air/ground, air/railroad combinations are also very common based on different products and locations. Other methods will be incorporated into the analysis in the future study. Based on this, cost comparisons can have different results.

So far, setup time in the simulation experiment has been ignored. Actually, setup time exists in most real world manufacturing systems. The total productive capacity will decrease when setup time exists. The results with setup time will be compared with the original results to evaluate its impact.

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