CHAPTER V

DESIGN PROCESS AND EVALUATION

5.1 Design Process Overview

From the analysis in chapter 4, many problems have been identified. The main problems are the large amount of time used for setup and complicated flow path created by the functional layout and the in appropriate location of the raw material storage and the office. These problems will be of the main focus when designing the new layout. One important factor that must be understood when designing the layout is the difference in production volume of the products. Because of the wide variety of parts being produced, the new layout will not be able to be optimised for all parts. The key is to design the layout that will provide the most benefits to the parts with the highest volume. When there is a need for orthopaedic surgery, the surgery normally uses more screws than bone plates. It can take up to seven or eight screws to hold the plates or rods in place. As for the instrument group, instruments are reusable, resulting in a relatively low demand. Therefore, the new design will set its first priority on optimising the flow path for the screw products. The second priority will be given to the bone plate products and the third priority to the instrument products. The travelling chart in section 4.2.4.4 has revealed this information systematically.

Two designs will be created. The first one will focus only on the cell formation concept to create a base plan to develop from. The second design will evolve from the first design using a hybrid cell formation approach to produce a more effective solution.

5.2 Design Concepts

5.2.1 Design #1 –Cell Manufacturing Base Plan

In this first design, the machines that have been identified as appropriate cell member in the process flow analysis earlier in section 4.2.4 will be placed in close proximity to each other to form the required cells. This design will not change the location of the office and the raw material storage as there are repositioning costs involved, but it will only tries to move the entry-point-machine as close to these locations as possible. This will be the only feature of this design. The reason behind this simple design is to create a base to develop upon. The first design will only apply minor changes to set the cell manufacturing concept in motion. Figure 5.1 on the next page below shows the new design – Design #1. Figure 5.1 shows that there are four distinct cells. The red and the green cells are the screw cells, the blue cell is this plate cell, and the purple cell is the instrument cell. The screw cells have been separated in two to reduce the cell size for ease of control. The green screw cell is for the cortical, compression and set screws; which do not requires milling operation. The red cell represents the pedicle and poly screw which requires milling operation. The machine placements within the cells were based on the information from the travelling chart. The improvement on this design compares to the original design is the grouping of CNC and manual machines to form the cells to reduce the setup time and simplify the parts' flow path.

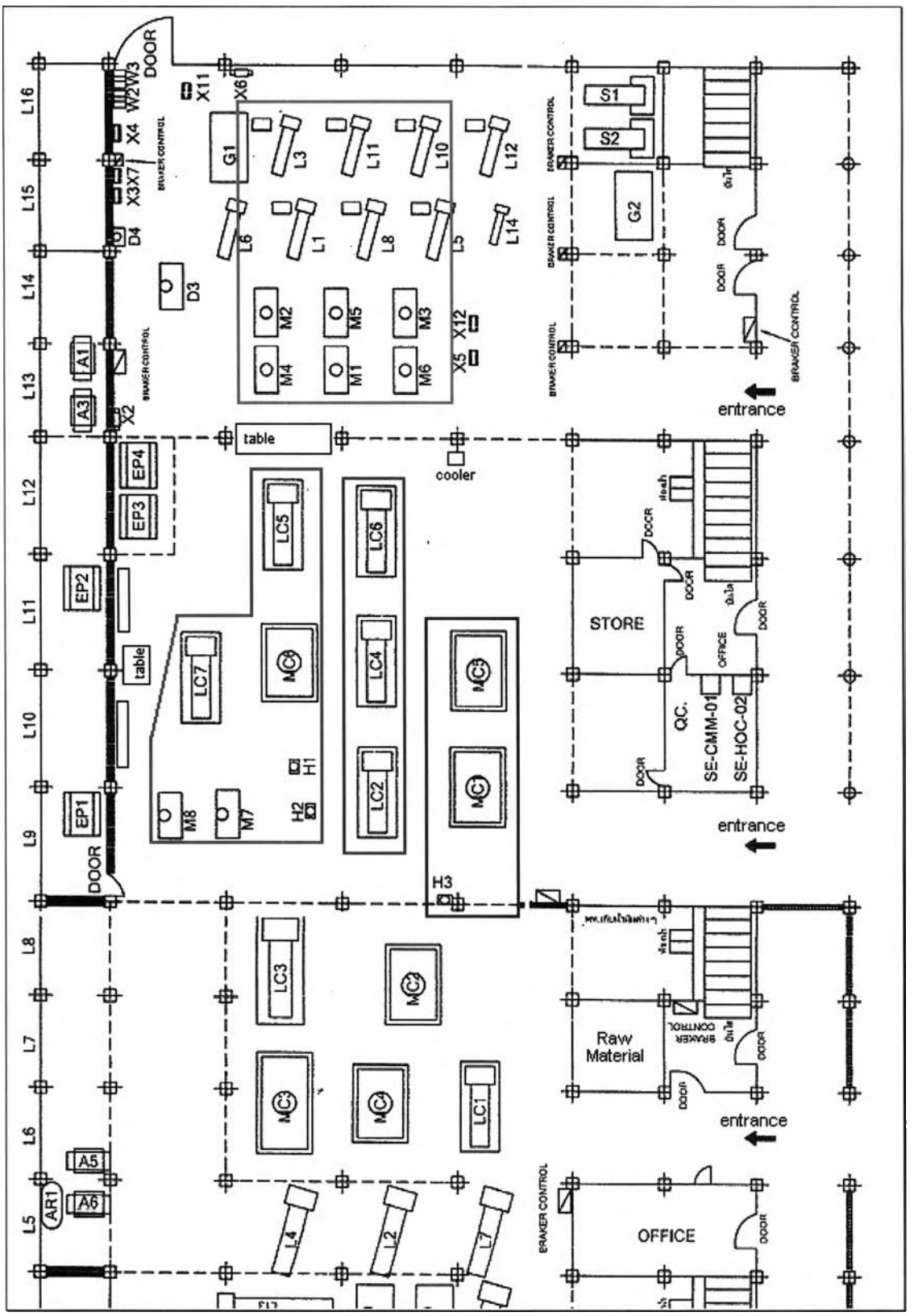

Figure 5.1 – new layout design based on cell formation concept.

5.2.2 Design #2 – Improved Machine Arrangement to Improve the Material Flow Path

In design #2, the machines placement has been improved to create a more streamlined product flow-path between the cells and other factory's departments. While sticking to the cell formation concept, the design has incorporated design features of the product layout. Although the cell manufacturing concept would already has created the shortest flow-path within the cells, the product layout concept has been chosen as an additional design philosophy because the cells themselves must be arranged so that it will fit in with other machines and departments that cannot be included in the cells. A pure product layout will provide the most effective manufacturing line while sacrificing manufacturing flexibility. By combining the cell formation concept and the streamlined features of the product layout, the design can gain the benefits from both manufacturing concepts without suffering too much from their respective set-backs. Design #2 is a refined version of design #1. Another feature that distinguishes design #2 to design #1 is the relocation of the office and raw material storage area. Although the distances between the machines have been significantly reduced through cell formation as design #1 have demonstrated, the distances between the office and raw material storage and the machines are still farther than desirable and there are room for improvement. The relocation of these two entities is considered necessary because the travelling chart has revealed that some of the most frequent transfers occur from/to the raw material storage area and the office. Therefore, one of the most effective design improvements can be achieved by improving the location of the raw material and office. The raw material storage location will be moved to an empty area in the factory and the office will be switched with the store room. Design #2 is shown in figure 5.2 on the next page.

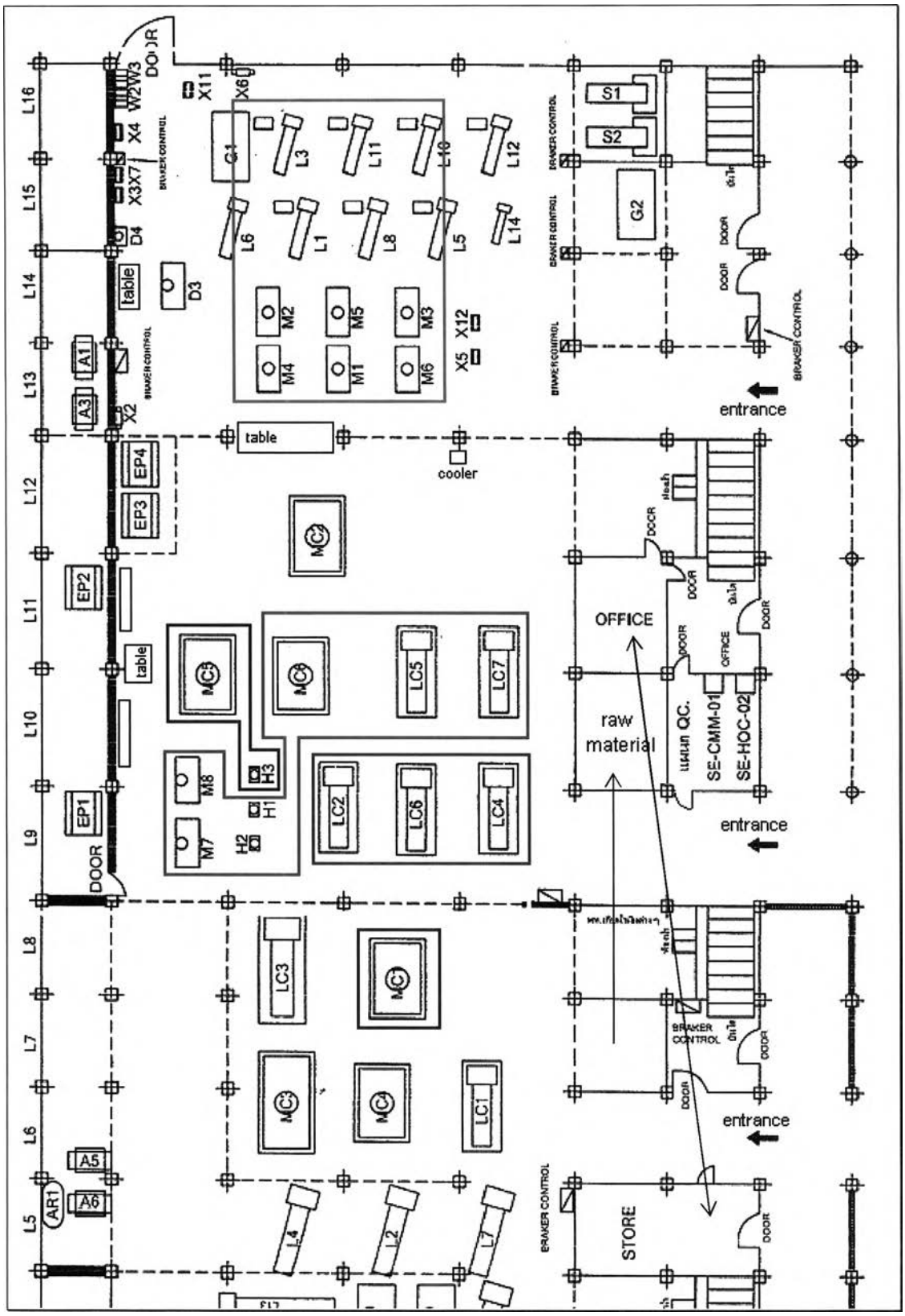

Figure 5.2 – new layout design based on hybrid cell formation concept with streamlined flow path.

Like the previous layout diagram, the red and the green cells are the screw cells, the blue cell is this plate cell, and the purple cell is the instrument cell. In this design, the blue (plates) cell has been separated. This was done to minimise the parts travelling distance. The separation of the MC1 from the MC5 and H3 will not affect the proposed cell concept as the two types of plates being produced, flat and curved plates, are mutually exclusive. Similar to the last design, design #2 aims were to reduce the setup time and to further reduce the travelling time and distances of the parts. The flow-path of the parts has been further simplified in comparison to design #1 (see appendix B for details).

5.3 Design Evaluation

With the design process completed, the new design must be evaluated for its performance. From initial analysis, through the cell manufacturing design principle, the new design has successfully reduced the setup time. Additionally as an extra benefit, the flow path has also been shorten and simplified. This section will go through the different improvements and cost of the new designs and analyses them in details. The different topics are:

1. Setup time reduction
2. Production capacity maximization
3. Extra profit gain from the extra capacity created
4. Product quality improvement through product ownership
5. Elimination of complicated machine allocation and scheduling
6. Movement of the office closer to the shop floor for better control
7. Manufacturing flow path simplification
8. Reduced product traveling time and distance
9. Implementation cost

5.3.1 Setup Time Reduction

The most important improvement gained by changing the layout from functional layout to cell manufacturing is the reduction in setup time. With the old functional layout, the machines were not allocated to any specific product. The machine operators will receive many different types of orders and the machines have to be setup for the each product. With each order, new CNC program have to be loaded and adjusted, tool has to be changed and machine have to be calibrated. The cell manufacturing layout will reduce the setup requirements as the machines will already be allocated to a group of products. There will be less product variety for each machine; hence the machines will not have to change its setup as often as before. And when there is a need to change the setup of the machine to produce another product in the same product family, the conversion will be less complicated and can be done much faster. Table 5.1 one the next page shows the setup time of each machine to re-setup the machine to produce another product in the same family. The original setup uses approximately 60-70minutes for CNCs and 30minutes for manual machines.

Table 5.1 – The new machine conversion time to produce another product in the same family [min]

	Screws					Plates		Instruments		
	poly screw	pedicle screw	compression screw	cortical screw	set screw	Curved plates	Flat plates	Pliers type	Small type	Screw driver type
MC1							15			
MC5						20				
H3										
MC6	8	8								
LC2				10						
LC4			10							
LC5	10	10								
LC6					6					
LC7	10									
H1										
H2										
Manual Milling	5	5						40	20	20
Manual Lathe								20	25	10

The setup time can be eliminated significantly. The cells only required one full setup to get it started. After that, only tool changes and minor product conversion are required to keep the cells running. The conversion time is very similar to the tool change time. Only minor program editing is required. Jig or fixture change is no longer needed. Table 5.2 on the next page shows that amount of time that can be saved. The calculation method is the same as when calculating the "actual available machine time" in section 4.2.4.2. The conversion time above is multiplied by the setup frequency and then deducted from the original setup time as shown in table 4.9, section 4.2.5.1.

Table 5.2 – The total setup time that can be reduced [min]

	Screws					Plates		Instruments		
	poly screw	pedicle screw	compression screw	cortical screw	set screw	Curved plates	Flat plates	Pliers type	Small type	Screw driver type
MC1							6448			
MC5						7642				
H3										
MC6	6088	4883								
LC2				13281						
LC4			11398							
LC5	5892	4725								
LC6					10389					
LC7	5892									
H1										
H2										
Manual Milling	2455	1969						414	411	7156
Manual Lathe								2070	411	2684

The time saved represents approximately 85% time saved from the original setup time. It should be noted that the savings in table 5.2 is only theoretical and is at the 'best case scenario' level. This level of saving may not be able to be fully realised as additional setups maybe required after the initial setup if events like machines breaks down or other unforeseen event occurs and the machine needs to be re-setup and recalibrated. However, breakdowns and accidental events cannot be predicted and as such is not included in this study.

5.3.2 Production Capacity Maximisation

As the result of the setup time saved by the new designs, this recovered time can be used for production instead. As table 5.1 have shown the total setup time saved, this setup time saved information together with the process time requirement information from the process flowcharts can be used to calculate how many extra units of each product can be produce. For example, if the total time saved for a machine is 40 minutes and the manufacturing process takes 10 minutes. Then the extra 40 minutes can be used produce 4 extra units. Table 5.3 below has been prepared to shows this information. The large figures that are highlighted in green are the lowest capacity gained values of all the machines that are used by a product (bottle neck). This is the real extra capacity value because no matter how much extra capacity the other machine can create, if the bottle neck machine that can only achieve X amount of extra capacity then that product will only achieve X amount of extra capacity

Table 5.3 – Extra capacity created from the setup time savings.

	Screws					Plates		Instruments		
	poly screw	Pedicle screw	compression screw	cortical screw	set screw	Curved plates	Flat plates	Pliers type	Small type	Screw driver type
MC1							716			
MC5						450				
H3										
MC6	553	488								
LC2				2214						
LC4			1628							
LC5	842	215								
LC6					1737					
LC7	589									
H1										
H2										
Manual Milling	40	394						1	2	183
Manual Lathe								62	51	62

5.3.3 Extra Profit Gain from the Extra Capacity Generated

As mentioned in the problem statement, the company is having a hard time meeting its demand. The company cannot produce enough units to supply to the hospitals. As such, potential profits have not been realised. Although the extra capacity generated from the setup time savings may not be fully sufficient to meet the high demand, but it will partially help the company to regain some of the potential profit. Using the extra capacity values in table 5.3 above and the profit margin of each product, the extra profit figure can be calculated, see table 5.4 below.

Table 5.4 – Table showing the extra profit from the extra capacity generated

	extra units	Profit margin [Baht]	Total profit [Baht]
Screw			
Poly	409	740	302660
Pedicle	215	590	126850
Compression	1628	35	56980
Cortical	2214	25	55350
Set screw	1732	4	6928
Plates			
Curved	450	380	171000
Flat	716	25	No demand
Instruments			
Pliers	1	980	No demand
Small parts	2	765	No demand
Screw drivers	62	1220	No demand
Total			**719768**

It should be noted that, only the screws products and curved plate will produce extra profit. This is because it is only these products that are experiencing the insufficient capacity problem. Even though extra capacity has been generated for the remaining of the product as well, if there is no demand for it, no profit can be realised. This is not to say that the extra capacity generated for these products is entirely useless, it may come in handy in the future especially with the growing trend of the company as these products may soon face a capacity shortage problem.

5.3.4 Improved Product Quality through Product Ownership

With the new designs, the functional departments have been eliminated and replaces with product-based cells. This will also bring forth changes to the management structure of the shop floor. With the functional layout, each department has a functional manager. i.e manual lathe and CNC milling manager. The functional managers are experts in their function but not in any particular product. With the new product based design, these managers will be assigned to a product family instead. Initially, there will be a steep learning curve to learn new functions and may cause some initial set back when the new design is implemented. However, as the managers come to terms with their product based responsibility, they will become experts at their products. This will lead to better product quality. Each manager will feel as if he is responsible for the outcome if his product. He is no longer just a small process in the manufacturing line. The product based approach will create a sense of product ownership for the managers which should stimulate them to perform better.

5.3.5 Elimination of Complicated Machine Allocation and Scheduling

With the old functional layout, the department managers are responsible for dispatching the orders to the machines he see fit as there are many machines available in a department; each varying in sizes and technical capabilities e.g. spin rate, tooling restriction, and tolerance limit. This may not seem like a problem if there is only one order at a time and the product can transfer from one department to another without having to wait. However, the factory has many orders that have to be completed simultaneously. There exists a need to synchronise the orders interdepartmentally. The problem with the current layout is that once an order has finished its operation in department A, it has to wait for the appropriate machine in the department B to

become available because it is very difficult to synchronise the production plan of the different departments. This is causing the factory to have a high level of WIP. With the new cell manufacturing designs, this problem can be eliminated. Since the functional department have been eliminated and instead, replaced with production cells which is practically a micro manufacturing line. The orders can move through the cell one at a time like a line production system. The manager can simply start the order at the beginning of a cell and let it run its course. Also, the machine that is best for the job has already been placed in its appropriate cell.

5.3.6 Office have been moved closer to manufacturing area making its easier for the manager to control the shop

This particular improvement is specific for design #2 only. Although this may seem like a very small improvement, it is very effective. Since the office has been moved closer to the production area (see figure 5.2 on page 63). The production manager is able to keep an eye on the production floor easier than before. As human nature would have it, the workers tend to work harder if they feel like they are being watched. The office repositioning will allow the manager to constantly monitor the shop floor and better keep things under control.

5.3.7 Flow Path Simplification

One of the extra improvement that is the result of applying the cell manufacturing concept is the simplification of the parts' flow path within the factory. String diagrams of the three different designs (original, design #1 and #2) have been prepared to provide a clear visual comparison of the old and new flow paths. Only some string diagrams will be shown here; like in chapter 4 before as its shear volume

makes it unpractical to show all diagrams here (see appendix B for the complete list of diagrams). Since there are three diagrams for each part (original, design #1 and #2), the order of the string diagram are arranged so that the part's three diagrams are grouped together for easy comparison. The first diagram in the group of threes will be of the original design, follow by design #1 and #2. The aim is to shows that the flow path get simpler as the diagram sequence progress. See figure 5.3 to 5.10. It should be noted that the string diagrams for the instruments product group for design #1 have not been created as there are no changes.

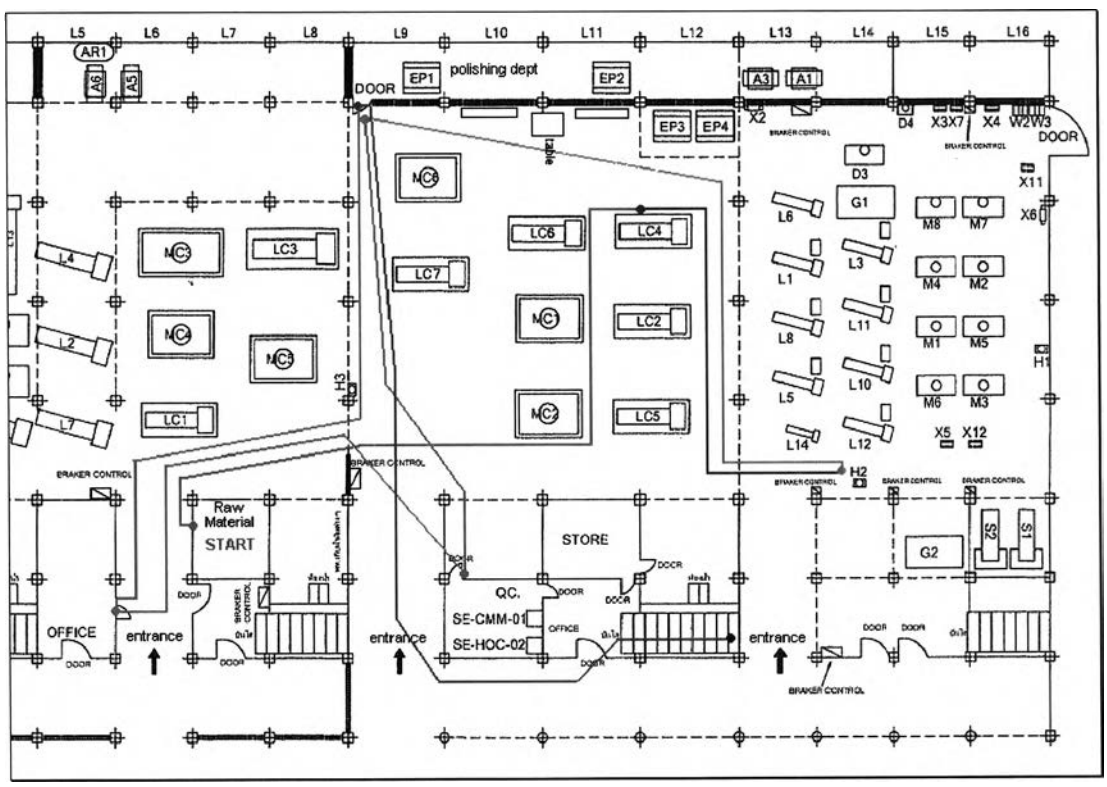

Figure 5.3 – Compression screw string diagram for the original design

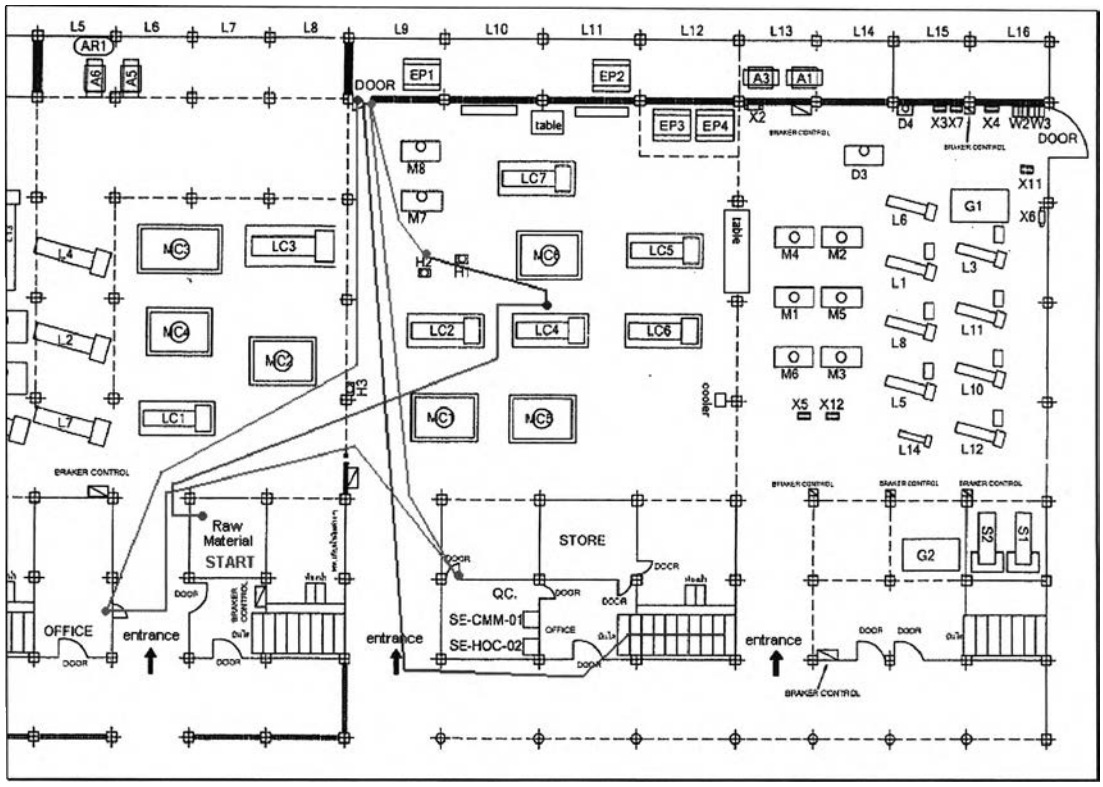

Figure 5.4 - Compression screw string diagram for design #1, note the improvement from the original design

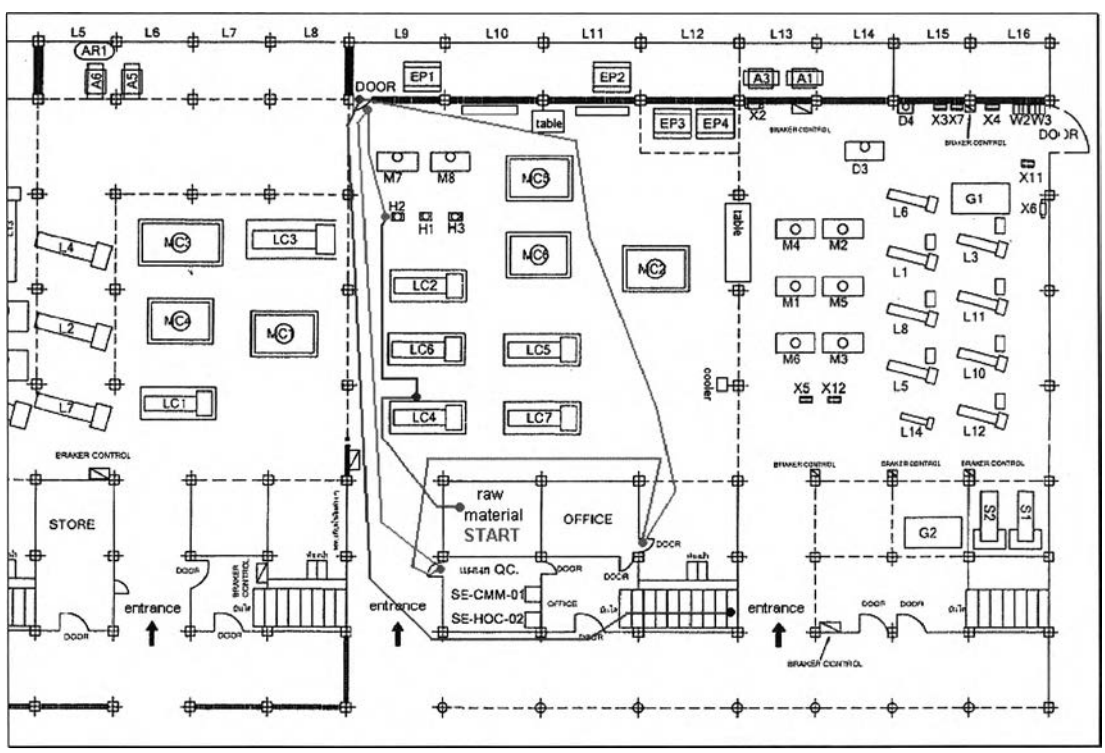

Figure 5.5 - Compression screw string diagram for design #2, note the improvement from design #1

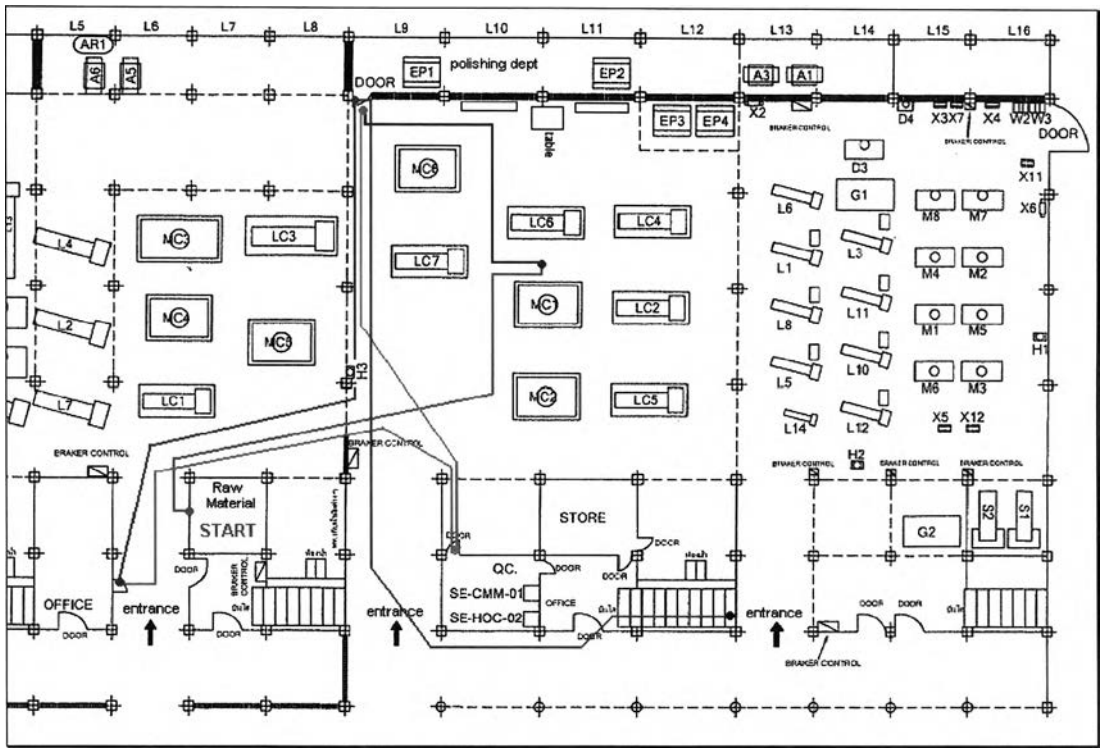

Figure 5.6 – Bone plate 8H string diagram for the original design

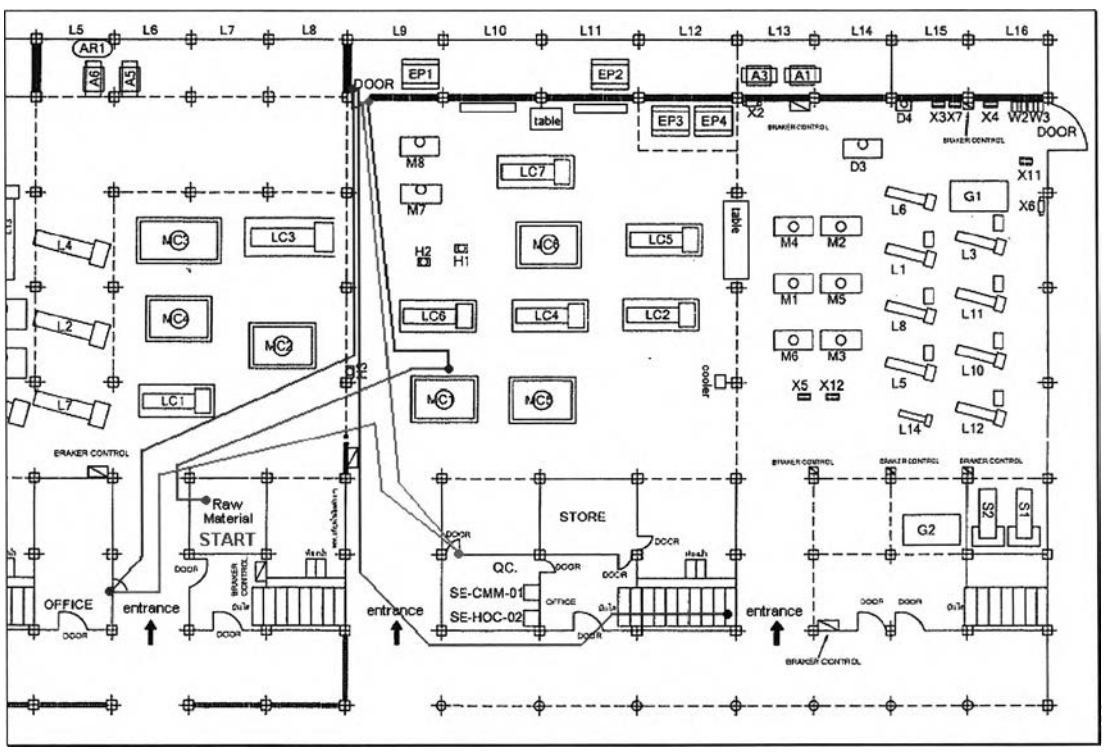

Figure 5.7 – Bone plate 8H string diagram for design #1, note the improvement from design #1

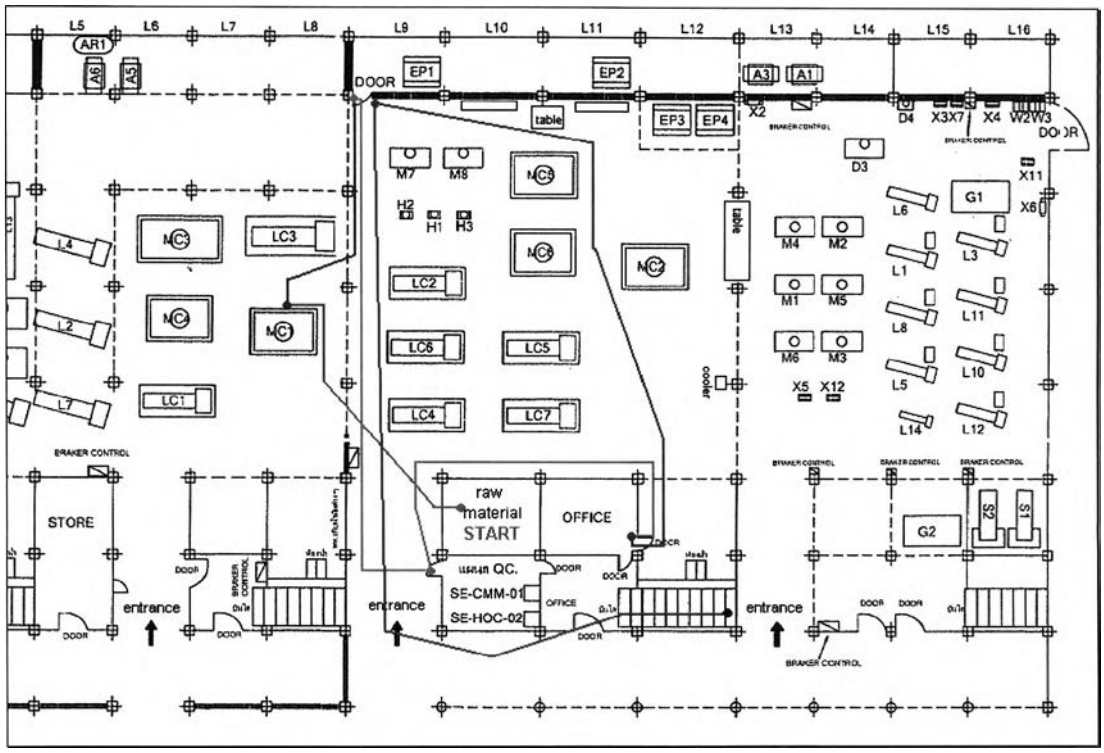

Figure 5.8 – Bone plate 8H string diagram for design #2, note the improvement from design #2

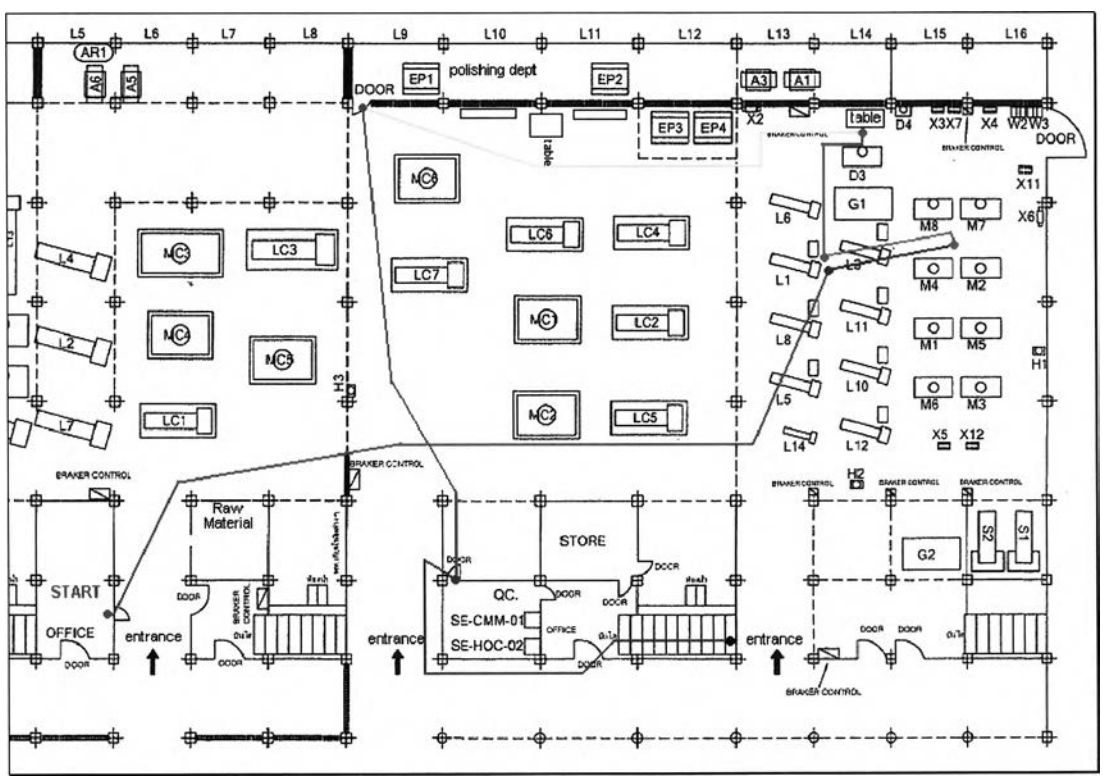

Figure 5.9 – Compression pliers string diagram for the original design

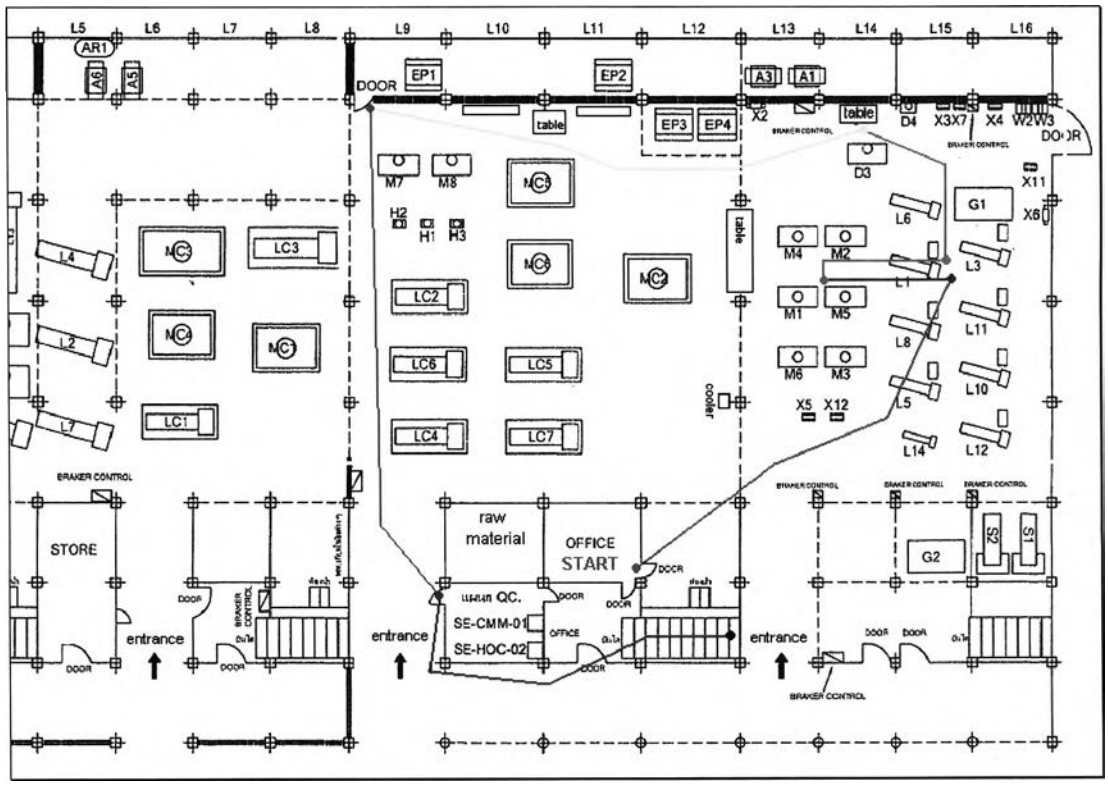

Figure 5.10 – Compression pliers string diagram for design #2, note the improvement from the original design

From the string diagrams shown here in figure 5.3 to 5.10 and those in appendix B, the two new designs have simplified the flow paths. This simplification will create a more organised working atmosphere on the shop floor.

5.3.8 Travelling Time and Distance Reduction

Another side benefits from the Cell Manufacturing concept is the reduction of the parts' travelling time and distance. With the machines located in cells, the travelling time and distance has been significantly reduced. Parts no longer have to travel across the shop floor to different departments. Most of the manufacturing processes have been placed as close to each other as practically possible with the exception of the polishing process which is placed in isolation outside due to ventilation requirements. As the result, the travelling distances and time have been significantly reduced. Table 5.5 below have been prepared to compare the absolute improvement of the two new designs and the original layout.

Table 5.5 – Table comparing the travelling distance of the original design and the two new designs and the distance and time saved.

	Original layout	Design #1				Design #2			
			Distance reduced by		time saved		Distance reduced by		time saved
	[meters]	[meters]	[meters]	[Percent]	[second]	[Meters]	[meters]	[Percent]	[second]
Screw									
Poly -body	328	193	135	41.13%	138.9	160	168	51.34%	173.5
- head	182	129	53	28.96%	54.3	97	85	46.70%	87.6
Pedicle	272	203	69	25.29%	70.9	170	102	37.56%	105.2
Compression	248	192	56	22.62%	57.8	163	85	34.35%	87.8
Corticle	239	184	55	23.01%	56.7	163	77	32.01%	78.8
Set screw	154	111	43	27.92%	44.3	84	70	45.71%	72.5
Plates									
Curved	195	192.6	2.4	1.23%	2.472	168	27	13.69%	27.5
Flat	198	185.6	12.4	6.26%	12.772	166	33	16.41%	33.5
Instruments									
Comp pliers	201	201	0	0	0	158	43	21.39%	44.3
Spine cage	160	160	0	0	0	123	37	23.13%	38.1
Inner hex holder - shaft	378	378	0	0	0	227.7	150	39.76%	154.8
- handle	182	182	0	0	0	85.1	97	53.24%	99.8

With design #1, the screw products have benefited the most with an average of 29% reduction in travelling distance. The plate products only lost an average of 4% improvement. Unfortunately, as design #1 did not make any changes to the location of

the manual machines, raw material storage and the office; there were no improvements gained by the instrument product group as their process requirement only involves these three entities which have not been altered from the original layout.

For design #2, further time and distance reduction from design #1 was achieved through the change in the location of the raw material storage area and the office. This repositioning also improves the instruments group unlike design #1. The catch with design #2 is the cost of relocating the raw material storage and the office. The screw products have benefited the most with an average of 41% reduction in travelling distance, the plate products obtain an average of 15% improvement and the instrument obtain an average of 34% improvement.

Still, the figures in table 5.5 do not accurately portrait the effectiveness of the new designs. The distance and time saved on each part must be multiplied by its volume to illustrate the total potential saving. For example, the design may save 50m on part A and 2m on part B. However, if there are 10 and 1000 batches for product A and B respectively, then the total distance saved on product B is much greater than product A; only 500m saving for product A and 2000m saving for product B. Table 5.6 below shows the total travelling distance of the original design and total travelling distance saved by the new designs.

Table 5.6 – Total travelling distance saved by the two designs

	Original distance	Design #1 saved [m]	Design #2 saved [m]
Screw			
Poly -body	40262	16571	20671
- head	22341	6506	10434
Pedicle	26775	6792	10057
Compression	58668	13248	20155
Cortical	84950	19549	27191
Set screw	32831	9167	15008
Plates			
Curved	17194	212	2354
Flat	29015	1817	4763
Instruments			
Comp pliers	10402	0	2225
Spine cage	16420	0	3797
Inner hex holder - shaft	84530	0	33611
- handle	40695	0	21667
Total	464081	73862	171933
Distance reduced by		15.92%	37.05%

Overall, design #2 is the one with the better performance. It outperforms design #1 by almost 57%. It provides a total distance reduction of 37%. The relocation of the raw material storage area and the office contribute significantly to this superiority.

5.3.9 Implementation Cost

Another important economic evaluation is the cost of implementing the design. Basically, the only cost incurred is the moving cost of the machines. The machines needed to be professionally moved as they are very heavy and cannot be simply moved using the factory workers. From the company's experience, a specialist machine mover using a forklift will be hired. The cost for moving one CNC machine is 5000baht and 3000baht for manual machines. Once the CNC machines are moved, they need to be connected to the power and air supply and recalibrated. This would

cost another 1200baht per CNC. The cost of setting up the manual machine is negligible, only a spirit level is needed to make sure that the machine is levelled. Furthermore, for design #2, there is an additional cost involved with the relocation of the office and the raw material storage area. The main relocation cost is from moving the steel cage and racks that is used to secure and store the raw material. The cages and racks would have to be modified to fit in the new area. This is approximate to cost around 20,000 to 25,000 baht. There are no significant cost involved with the switching of the office and the store room. Only labour is needed to move the furniture and equipments. A cost summary table is shown below, table 5.7.

Table 5.7 – Cost summary table for the two designs. Design #2 is more expensive as there is extra office and raw material storage area repositioning cost.

	Design #1		Design #2	
	details	cost	details	cost
Machine moving cost	9 CNC 2 Manual	= 45000baht = 6000baht	9 CNC 2 Manual	= 45000baht = 6000baht
Machine wiring and calibration	9 CNC	= 10800baht	9 CNC	= 10800baht
Storage area relocation		0baht		22000baht
Office relocation		0baht	2 workers for one day	400baht
Total		61800baht		84200baht

Looking only at the absolute value, design #1 may seem like it is better since it is cheaper. However, when the difference of 22400baht is weighted against the superior travelling time saved, the cost of design #2 is justified.