Improvement of Hard Drive Component Packaging by Using Six-Sigma Methodology

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Abstract

The objective of this research is to improve the packaging of the head stack assembly (HSA) that is a major component in hard drives. Six-Sigma methodology is applied to develop the new packaging concept and design that can reduce freight and packaging costs. The research starts with searching for appropriate quality improvement characteristics that can be used to solve packaging problems in both macro and micro levels. All factors related to customer requirements are prioritised. The factors with the most impact or the objective are selected for further analysis and improvement. The new packaging concept developed from the research substantially changes the original design. The type of packaging was changed from group packaging to transport packaging. The new concept is tested and evaluated with statistical analysis. It was also validated to assess any negative impact that may occur. Evidence shows that the new packaging can reduce packaging and freight cost per HSA from 0.598 USD to 0.156 USD and from 0.582 USD to 0.205 USD, respectively.

Keywords: Six-Sigma, packaging

1. Introduction

Packaging is a very important part in the manufacturing industry. A company can not maintain the quality of products without good packaging. Good packaging can help the company enhance its product competitiveness in terms of quality, reliability, and cost.

The head stack assembly (HSA) is one of the most sensitive parts of hard drives in handling and transportation. Good protective packaging is necessary to maintain the quality of products both during manufacturing and transportation. Hence, HSA packaging has to be designed and selected appropriately. If the packaging is too good, the packaging cost incurred will be unbeneficially high. In order to find an appropriate packaging, the design engineer needs to understand and acquire all necessary requirements related to products, processes, and transportation.

This research will describe how to develop the new HSA packaging concept that not only can reduce the cost but also enhance the company competitiveness by using a systematic quality improvement method, i.e. Six-Sigma. The major customers for this product are the hard drive factories in Singapore and China. Moreover, the customers in this project also include shop floor workers in packaging areas, freight forwarders, material planners, quality engineers, and other people that are concerned with HSA packaging activities. The new design will be analysed and validated by simulations including both physical and computer simulations to shorten the packaging development cycle time.

2. Research Background

A U.S. hard drive manufacturer was established as the case study company. The company has manufacturing plants in US, Ireland, Singapore, China, and Thailand. Its policy is to segregate the components of the hard drive to build and assemble in various countries. Read and write components (wafer and slider) are built in US and Northern Ireland. Recording head (HGA and HSA) that is the most sensitive part to handle is assembled in Thailand. Recording media (disc) and motor are built in Singapore. PCB assembly is done in Malaysia. Finally, all components are shipped to the hard drive assembly plants in China, Singapore, and US. Shipping components being assembled in different countries costs a lot of money, especially on freight and packaging costs.

HSA is a very fragile part; so it requires a special packaging for shipping to another site. Moreover, the new trend of technology requires a smaller hard drive with bigger capacity. This makes HSA even more fragile and requires better protective packaging to transfer. The defect rate from damaged HSA occurring during transportation is around 3-5%. To reduce such defects, the company has to use extra cushion packaging. As a result, packaging and freight costs are increased dramatically. During the last three years, these costs per HSA have been increased from 0.18 to 0.58 USD. This made the company spending increase to about 6.8 million USD per annum.

Figure 1 shows the comparison between current packaging and the extra cushion packaging. The extra cushion packaging has a huge impact on packaging and freight costs. Mainly, it reduces the capacity of the shipping pallet from 1,080 to 720 HSA per pallet. This is because the size of the box is very big and it takes a lot of space on the shipping pallet.

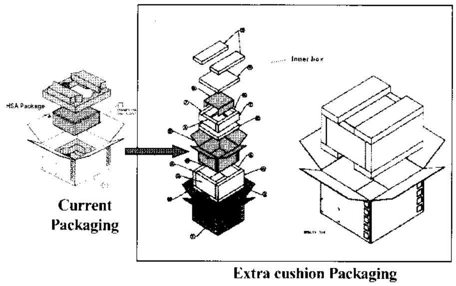


Figure 1: *Comparison between current packaging and extra cushion packaging*

3. Six-Sigma in Packaging Improvement

Many problem solving tools and quality improvement methodologies are currently exercised in practice, i.e. kaizen, quality control circle, total quality management, etc. These approaches have been renowned in helping the company to establish long-term continuous improvement. Obviously using solely one of these quality improvement methodologies may not be effective enough to gain abrupt competitive advantage. As a result, the company has to search for an alternative to achieve breakthrough improvement within a short time. One of the solutions is Six-Sigma.

In fact, there is nothing new or unknown in Six-Sigma. Six-Sigma is a combination of quality improvement tools and techniques. It includes the philosophy to select the improvement project that has the most effect on the company's benefits. Six-Sigma philosophy can encourage people to search for breakthrough improvement. Nothing is good enough until it can reach 3.4 defects per million [5]. It was found that not many Six-Sigma projects can reach this quality level, but most of the Six-Sigma projects can achieve breakthrough improvement.

Packaging has been an untouched area that is left without improvement in many companies for a long time. Nowadays, competition forces the company to look for cost saving activities in all areas including packaging as well. It is clear that product cost has to be reduced as much as possible to gain competitive advantage and deliver more value to the customer. The big question is how we can improve packaging cost quickly. This is because packaging is concerned with many organisations both inside and outside the company. Therefore, effective tools or guidance that can improve packaging quickly and effectively is needed.

Six-Sigma is a good methodology to establish long-term improvement. It can be applied and has strong impact on many levels in the company. When talking about Six-Sigma, many peoples think that it is about DMAIC (define, measure, analysis, improvement, and control) problem solving processes. It is true, but Six-Sigma can be applied for the higher business level (macro level) too [8]. There are three levels of Six-Sigma objectives including: (1) *business transformation:* it affects a major shift in how the organisation works or the cultural change; (2) *strategic improvement:* it targets key strategic, operational weaknesses or opportunities; and (3) *problem solving:* it is used to fix specific problematic areas of high cost, rework or delay.

Six-Sigma in the micro level is mostly presented with the DMAIC problem solving process steps. Moreover, for the problem that may require a process change or design change, the Six-Sigma process steps can be adapted to DMADV (define, measure, analyse, design, and verify). Many literatures call this DMADV "design for Six-Sigma (DFSS) process" [2, 3]. To analyse and improve packaging in a wide perspective, we need to understand packaging problems in detail and then apply the Six-Sigma concept to that key issue appropriately. In addition, the Six-Sigma concept at macro and micro levels has to be combined synergistically to solve the problem effectively.

4. Six-Sigma (Macro)

The objective is an design a new packaging that can reduce both packaging and freight costs. To achieve the goal, the current packaging design has to be studied thoroughly, especially about its purposes, how it is handled and transferred, and who are the concerned persons in the packaging area [6].

Process mapping is the effective tool that allows designers to understand the current process. The process is started from the raw material receiving point to the points where HSA is built and shipped to customers. The study also includes the reuse process (Fig. 2)

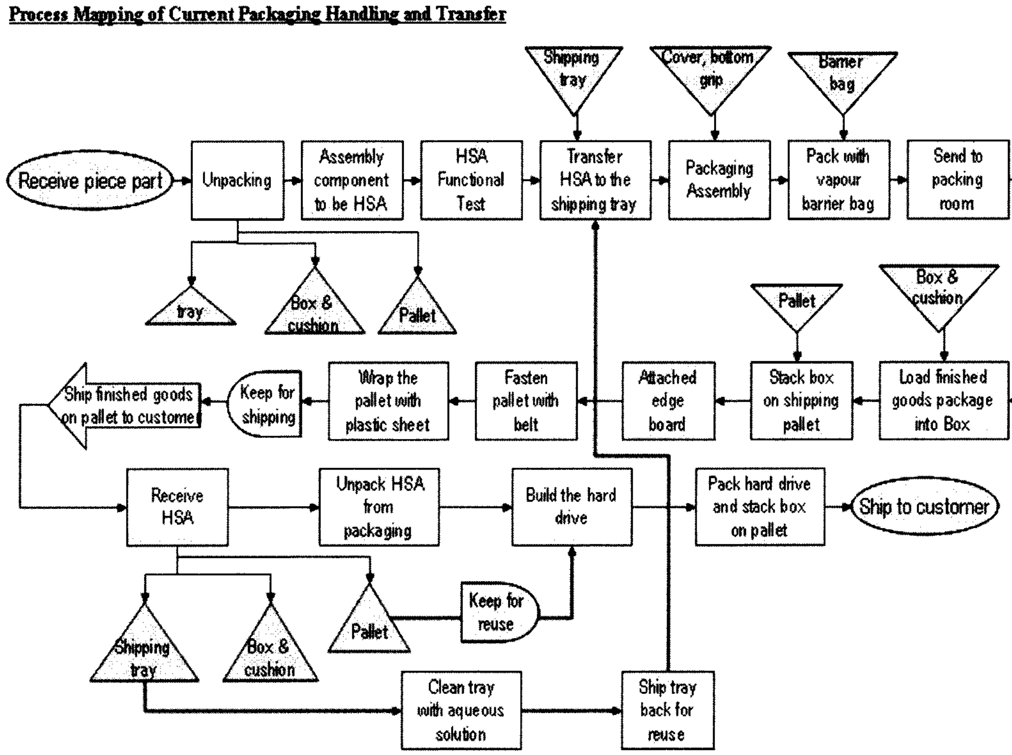


Figure 2: *Process mapping of packaging handling process*

Three types of packaging are defined in industries including primary, secondary, and tertiary packaging [1]. Tertiary packaging is often called "transport packaging". The current HSA packaging is designed to conform to the secondary packaging standard. It is qualified by using a free-fall impact test (drop test). Under the test, packaging is dropped ten times in different directions without the pallet. From the process mapping, it is clear that defining HSA packaging as the secondary packaging is not right because the company has to ship all HSA packages on the pallets. Carton boxes with HSA packages inside are stacked on the pallets, fastened with belts, and then wrapped with plastic sheet. The pallet assembly is transferred from the gate of the HSA plant to the incoming gate of the HDA plant without disassembly. Since HSA packaging in mass production is always shipped on the pallet, it is better defined as "transport packaging".

The goal in transport packaging is to provide the correct design for packaging which can ensure that the product will arrive safely at its destination, without using too much or too little packaging material [9]. As a result, during the design process, all requirements of transport packaging have to be considered including: (1) product production, (2) ease of handling and storage, (3) shipping effectiveness, (4) manufacturing efficiency, (5) ease of identification, (6) customer needs, and (7) environmental responsibility.

Having conducted brainstorming with the cross-functional project team, a QFD table is generated. Normally, there are 4 levels of QFD processes [12], i.e. (1) *1st house:* transferring customer requirements to design requirements; (2) *2nd house:* transferring design requirements to part characteristics; (3) *3rd house:* transferring part characteristics to key process operations; and (4) *4th house:* transferring key process operations to production requirements. In this research, it is not suitable to generate all four houses of quality for packaging improvement project because many requirements need to be improved at vendor sites. The team decides to generate the 1st house of QFD and selects only the items that are related to design requirements (Table 1). The specifications of each design characteristic are put into the QFD table. This information is also useful if the part characteristics need to be generated in the 2nd house.

Packaging and freight costs per HSA are used as the primary measurements. In addition, the percentage of head damage defects is used as the secondary measurement. In the past, the company calculated packaging cost per HSA from the secondary measurement. With the transport packaging concept, the way for calculating packaging costs per HSA has to be changed to the cost of packaging per pallet divided by the number of HSA per pallet.

5. Six-Sigma (Micro)

Currently, there is no packaging that is designed based on transport packaging criteria. To get breakthrough improvement, the DMADV process is exercised.

Define Phase

HSA packaging comprises many components. The one with the most effect on the cost is selected for the improvement project. To generate substantial improvement in cost, the improvement project is linked to the company spending. The actual expenditure of each packaging component is as follows: the tray (66%), carton box (23%), cushion (10%), and

others (1%). As a result, the tray is the main component on which the project is focused.

To get breakthrough improvement, cooperation from every group of people who are concerned with the packaging improvement is needed. In addition, the team needs strong leadership and support from top management, authority from the organisation, enough knowledge and adaptability skill to find out the solution, and good quality improvement culture from the concerned areas. The team requests that everybody must search for improvement from his/her responsibility. The packaging requirements are separated and forwarded to each of them. Figure 3 shows the structure and linkage of the packaging improvement team.

Table 1: The 1st Level QFD (Customer Requirements to Design Requirements)

Design Planning
Product: Packaging

1st House
Design Requirement

Importance of the Hows is "Importance Rating *Sum of Relationships/20"

HOWs / Inputs → WHATs / Outputs ↓	Kano Analysis	Importance	Meet Shock load requirement	Meet vibration test requirement	Meet cleanliness specification (LPC)	Meet out-gassing specification	Protect Electrostatic Discharge	Protect contamination	Tray should be stacked firmly	Quantity of part per box	Save space to storage	Weight of shipping pallet assy	Universal packaging	Number of packing assy part	Readable identfication	Small lot size	No bad smell	Can be reused	Can be recycle (material level)
Direction of Improvement			↑	↑	↓	↓	✖	✖	✖	↑	↓	↓	✖	↓	✖	↓	✖	↑	✖
Customer Requirements																			
Product Protection	MB	10	9	9	9	9	9	9	9		1	3			3				
Ease of Handling and Storage	MB	4							3		9	9	9	3		3			
Shipping Effectiveness (low freight cost)	1D	7							1	9		3	1						
Manufacturing Effciency (low labour cost)	1D	6							1	9	9	3	3	9			3		
Ease of Identification	MB	5											1		9				
Can ship with all transportation modes	MB	5	9	9							1	3					3		
Can carry sufficient information	MB	8													9				
Can do quality audit	MB	5								1		1		3	1	3			
low pacakaging cost	1D	8							3	9		1	3	3				9	3
Compatible with current process	MB	6	3	3	9	3		1	3	3	1	3		1			1		
Environment Responsibility	MB	3	1	1	1	3	1			1	1			1			9	9	9
Importance Rating			156	156	147	117	93	96	157	215	114	151	90	114	152	27	66	99	51
Importance of the HOWs			8	8	7	6	5	5	8	11	6	8	5	6	8	1	3	5	3
Objective Measures																			
Units			G.	Hz.	particle /cm2	ng/cm2	Ohm	enclose	include	unit	m3	kg.	include	piece	include	unit	include	include	include
Target													Y						Y
Lower Limit			100	300						45	1.7								
Upper Limit				3	500	770	10^5	Y	Y		1.9	326		6	Y	120	Y	Y	

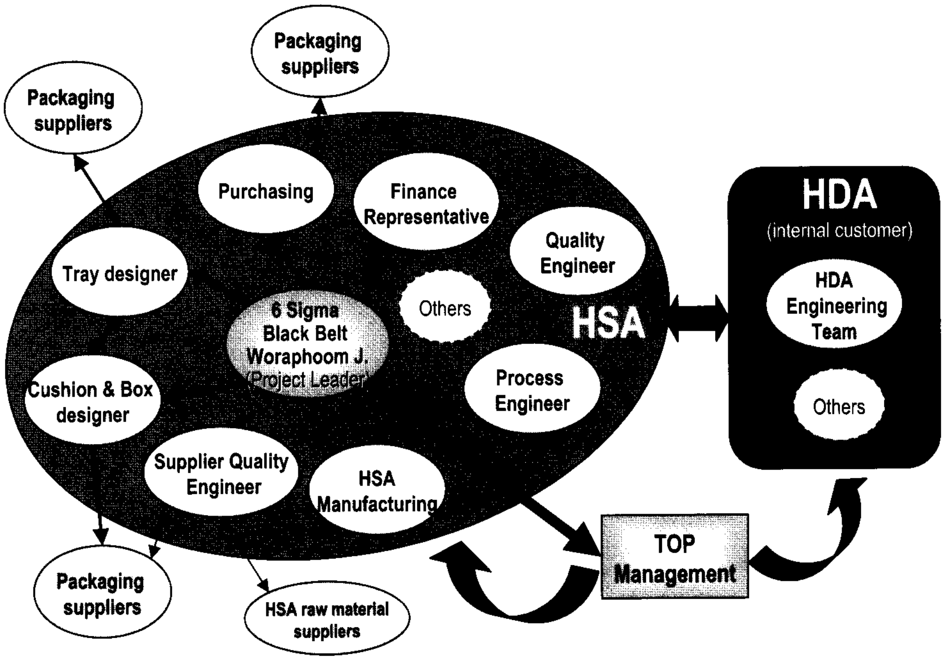


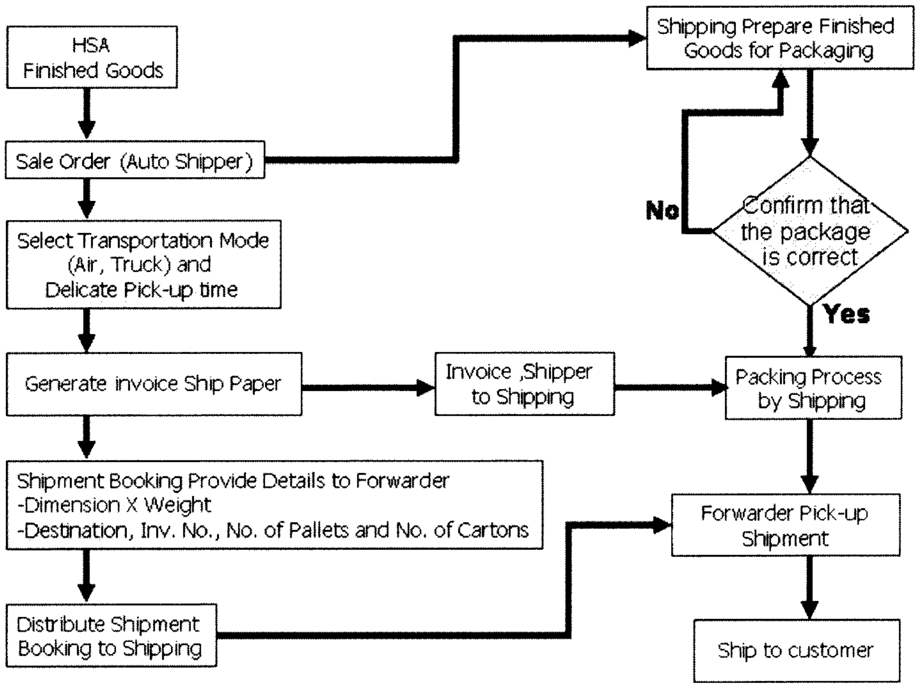
Figure 3: *Linkage among team members*

Measurement Phase

Pallet assembly is the major factor that the company uses for calculating freight cost. The freight forwarder (logistic company) quotes the freight price by using the volume of completed pallet assembly. Generally, if the weight of pallet assembly is more than 326 kg., the freight forwarder will quote the price from the actual weight. In contrast, if the pallet assembly's weight is less than that, the freight forwarder will quote the price by using the outer dimension of the pallet assembly. Since HSA's weight is light, the total weight of the pallet assembly is always less than the triggering limit of weight charge. Hence, to get the lowest freight cost per HSA, packaging that contains more HSA per pallet is needed.

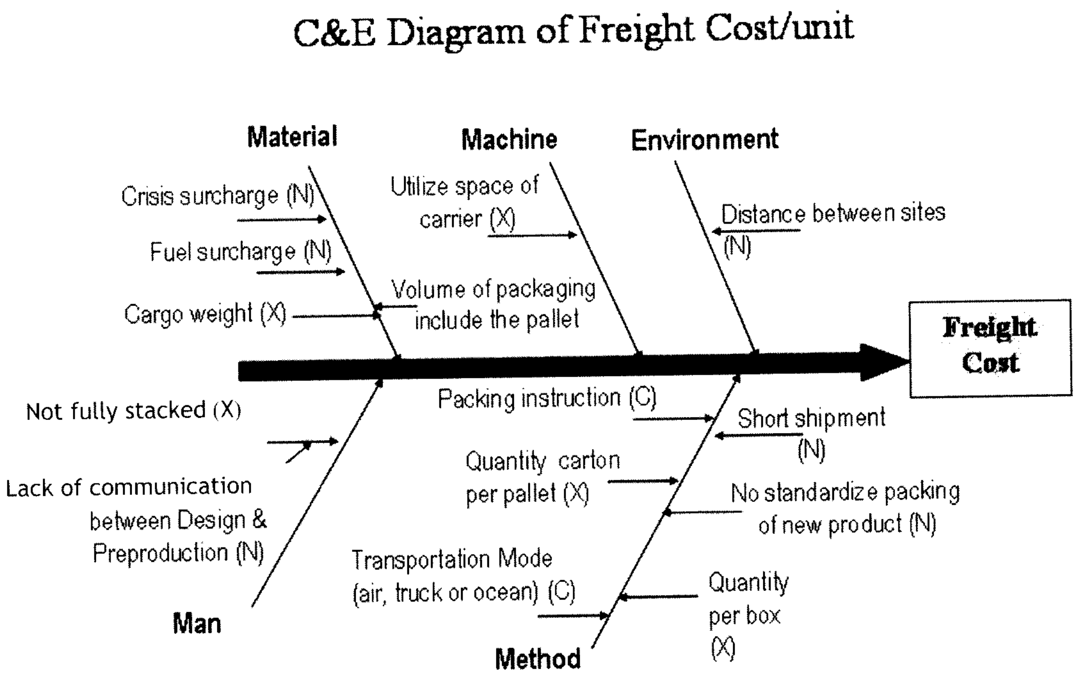
To help everyone understands which activities (steps of generating invoice through shipping HSA to the customer) incur high freight cost, the process mapping of shipping HSA, cause and effect diagram, and FMEA are drawn (Fig. 4). The higher number of RPN means more important issue that should be focused. From Fig.4, the first four major issues are about the quantity of HSA per shipment. On the other hand, the fuel and weight charges are less important. Since the existing packaging is designed with a secondary packaging concept which is undesirable, the team decides to design a new packaging by using the transport packaging concept and also applies the design for Six-Sigma process (measure, analyse, design, and verify) as the design improvement process.

Process Mapping



Process or Product Name:	HSA	Prepared by: Pornlapat N.	Page _1___ of _1__
Responsible:	Woraphoom J.	FMEA ______ (Rev) _1__________	

Process Description/ Function	Potential Failure Mode	Potential Effects of Failure	SEV	Potential Causes of Failure	OCC	Current Controls	DET	RPN	Action Priority	Corrective Action
Sale Order (Auto shipper)	Low number of part per invoice	too many invoice	2	special SBR, build schedule not match with shipping schedule	8	Issue invoice 1 time a day	3	48		
Select Transportation Mode (air / truck)	High freight cost	High freight cost per HSA	7	Urgent request from customer, incorrect default transportation mode	5	Manage to ship with truck as the default	4	140	4	Improve accuracy of requirement and build plan
Generate invoice	delay the shipment	Shipment delay and need to change from truck to air shipment	6	incorrect invoice	3	Auto shipper	3	54		
Shipping Prepare Finished Goods for Packing	Finish good not enough to ship the full pallet	High freight cost per HSA	7	Production miss output, low volume build, short shipment	5	waiting until pallet is full	4	140	4	Set mimum total height of pallet before ship
	Incorrect packing	Delay shipment and high freight cost	7	operator selects the wrong box	3	Supervisor informed	4	84		
			7	No standardize packing of new product	5	Supervisor informed with reference document	3	105	5	Implement the universal packaging
Shipment Booking, Dimension, weight, Distination, no. of parts per pallet	high freight cost	Ship to wrong destination	8	human error, lack of communication	1	Check with build plan	2	16		
		Not utilize space of carrier	7	Low quantity of carton per pallet	9	Operator check	6	378	1	Increase number of boxes per pallet
			7	Quantity of HSA per box not full	7	Build plan per shift	7	343	2	Increase number of HSAs per box
			7	Unfully stack tray	5	Refer to official drawing	6	210	3	Increase number of trays per stack
			7	Volume of package with pallet	7	Check that it not exceed maximum height	6	294	3	Design the package with appropriate dimension
		High airfreight charge	7	High crisis and fuel surcharge	3	Global rate	1	21		
			7	Heavy weight packaging	1	Freight forwarder cross check	1	7		



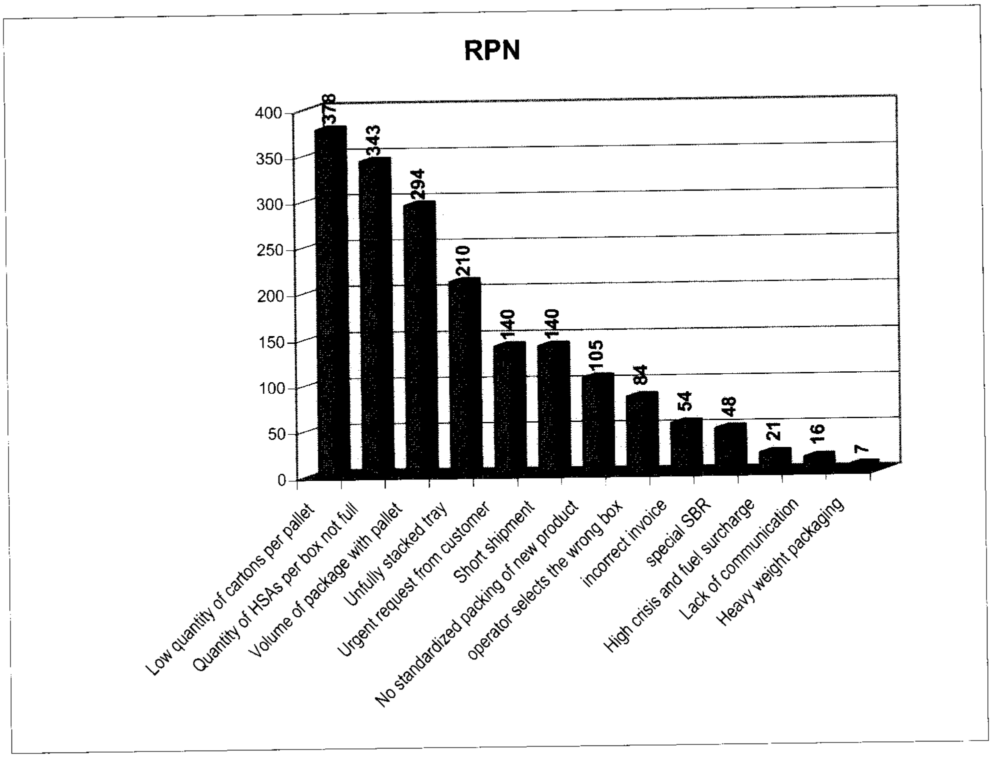


Figure 4: *Process mapping, C&E diagram, and FMEA of freight cost*

Analysis Phase

According to the transport packaging concept, the robustness of product can reduce the level of packaging requirements. The team uses CAD to conduct finite element analysis of the product. The simulation result shows that vibrating HSA in the horizontal direction is more fragile than in the vertical direction (Fig.5).

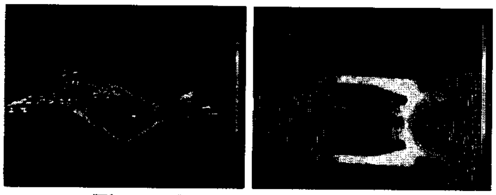


Figure 5: *Finite element analysis*

The team decides to test this hypothesis by comparing the packaging performance under vertical packing and horizontal packing. For evaluation purpose, the gram-load of HSA (the spring force of arm actuator body required for setting the appropriate gap between recording head and media disk), is used as the primary measurement. This is because the gram-load is variable data (using variable data can reduce the sample size of HSA for testing). Two-sample t test [7] is selected for statistical analysis. The result indicates that the mean gram-load change between vertical oriented packaging is not significantly different with that of horizontal orientation (p-value = 0.873).

The variation of the gram-load change between these two groups also needed evaluation. Interestingly, many outliers of the gram-load difference are found from horizontal orientation compared a vertical one. This is not good since it indicates a high chance of future head damage failure. F-test analysis is used to test the equality of variance between these groups. It is found that vertical orientation can reduce the variation of gram-load change significantly (p-value = 0.000). Therefore, HSA is more robust if it is shipped with vertical oriented packaging. The team requests the designer to design the packaging that holds HSA in the vertical direction.

Another important factor observed from benchmarking analysis is the weight of packaging. Generally, impact momentum ($mv = m\sqrt{2gh}$) and impact energy ($e = mgh$) depend on the mass m of the dropped part and the height h through which it is lifted [4]. The lifted height will control the final velocity v of the dropped part when it contacts the ground. The impact energy in the drop test is the representative of distribution environment of the dropped package. Because of the standard height in the drop test is fixed at 12 inches, the factor that can reduce the impact energy from drop is the weight ($W = mg$). Therefore, the weight the of the HSA package should be reduced also.

Design Phase

Having understood the effect of key process input variables (KPIV) on the packaging performance, the team knows the main design requirements that should be focused on in designing HSA packaging. The team also forwards all requirements presented in the QFD format [11, 12] to the packaging designer to demonstrate the parameters that are directly related to customer's criteria item by item.

By using QFD, the requirements can flow down to sub-component level. The cushion and box engineer can use these requirements to design a box and a cushion in detail. Furthermore, the tray designer can also draw another house of QFD to design and deliver a better tray. Since there is only one engineering team who takes care of both cushion and box design in the company, the QFD of the cushion and box are combined together. The QFD deployment flow is presented in Fig. 6 and Table 2.

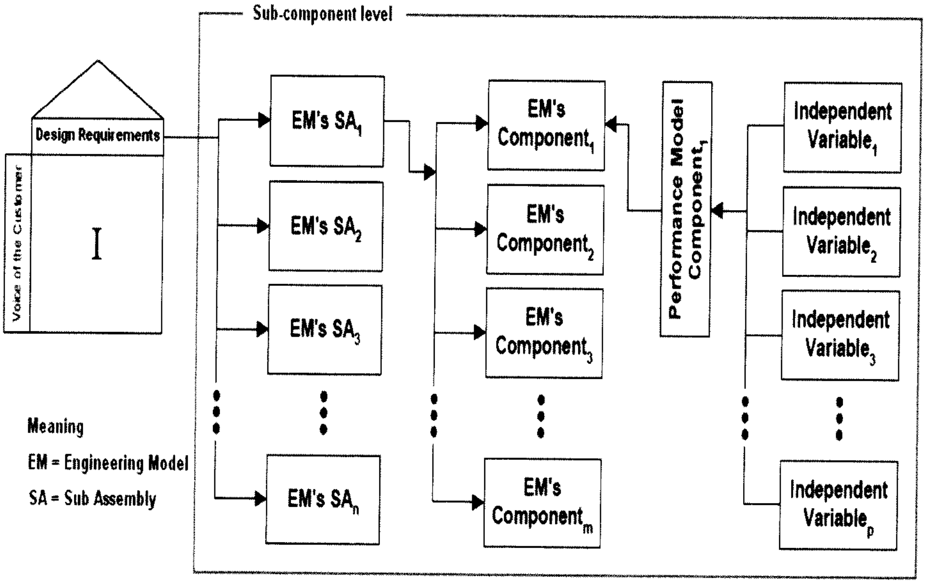


Figure 6: *QFD deployment flow*

Table 2: *QFD of part planning for component level*

Part Planning

Importance of the Hows is "Importance Rating *Sum of Relationships/20"

	HOWs / Inputs			Cushion									Box					
	WHATs / Outputs	Kano Analysis	Importance	Cushion density	Cushion thickness	Cushion Elongation	Dampening feature	Number of cushion parts	Weight of cushion	Dimension not change after use	Recycle material	Hold HSA in the vertical direction	No open gap on the box	Weight of box	% utilisation of Shipping space	Readable barcode & symbol	Dimension not change after use	Recycle material
	Direction of Improvement			✖	✖	✖	✖	↓	↓	✖	✖	✖	✖	↓	↑	✖	✖	✖
Design reuirements	Meet Shock load requirement	MB	8	9	9	3	9	1	3	9		9	3	9			9	
	Meet vibration test requirement	MB	8	9	9	3	9	1	3	9		9		3			9	
	Protect contamination	MB	5										9					
	Should be stacked firmly	MB	8							3					9		3	
	Quantity of part per box	1D	11		9			1						1	9			
	Save space to storage	1D	6	1	3			3		1	1	3			9			1
	Weight of shipping pallet assy	1D	8	3	3				9					9	3			
	Universal packaging	ATT	5	3	3	3	1	3				1			1	3	1	
	Number of packing assy part	1D	6				3	9										1
	Readable identfication	MB	8													9		
	No bad smell	MB	3	1							1							1
	Can be reused	MB	5	1	1	1		3	3	3						3	9	
	Can be recycle (material level)	ATT	3	1	1	1		·3	1		9	9						9
	Importance Rating			200	308	71	167	138	138	189	36	194	69	179	254	102	218	42
	Importance of the HOWs			10	15	4	8	7	7	9	2	10	3	9	13	5	11	2

Part Planning

Importance of the Hows is "Importance Rating *Sum of Relationships/20"

	WHATs / Outputs \ HOWs / Inputs	Kano Analysis	Importance	Tray: Liquid Particle count (LPC)	Out-gassing requirement	Surface resistivity	Has stacking feature	Total Height of stacked tray	Perimeter of tray (width)	Perimeter of tray (Length)	Quantity of HSA per tray	Weight of tray	Dimension not change after use or clean	Recycle material
	Direction of Improvement			↓	↓	✖	✖	✖	✖	✖	↑	↓	✖	✖
Design requirements	Meet Shock load requirement	MB	8				9	3			3	9	9	
	Meet vibration test requirement	MB	8				9	3			3	9	9	
	Meet cleanliness (LPC)	MB	7	9	1	3	3							3
	Meet out-gassing specification	MB	6	1	9									3
	Protect Electrostatic Discharge	MB	5	3		9								3
	Protect contamination	MB	5	9	9	3	3						3	
	Tray should be stacked firmly	MB	8	3			9	3					3	
	Quantity of part per box	1D	11				3	9	9	9	9	1		
	Save space to storage	1D	6				3	3	3	3	9			1
	Weight of shipping pallet assy	1D	8								3	9		
	Universal packaging	ATT	5					9	9	9	3			
	Small lot size	ATT	1								9			
	No bad smell	MB	3		9									1
	Can be reused	MB	5	3		3	3						9	
	Can be recycle (material level)	ATT	3											9
	Importance Rating			168	133	93	312	225	154	154	243	219	223	86
	Importance of the HOWs			8	7	5	16	11	8	8	12	11	11	4

Tray:

The new tray should include the requirements that are listed in the QFD. Each item is analysed and has the solution as listed in Table 3.

- *Stacking feature:* The stacking feature is included in the new tray design to make sure that the tray is stacked firmly. The picture of design evaluation is shown in Fig.7.

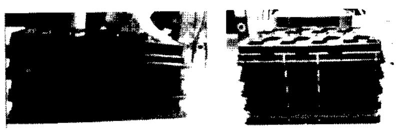


***Figure 7:** Stacking feature of HSA tray*

- *Quantity of HSA per tray:* There is a gap between each HSA cavitiy. When the gap is reduced, the quantity of HSA per tray can be increased from 6 to 8 (Fig. 8).

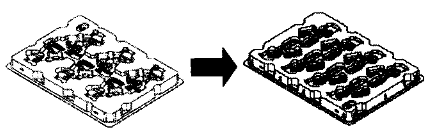


***Figure 8:** Increased tray cavities*

- *No dimension changes after use:* The team tries to increase the robustness of the tray to extend its life cycles (Fig.9). This also helps reduce the cost of the tray because it can be reused several times before getting damaged.

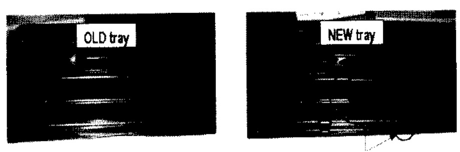


***Figure 9:** Feature of the tray*

- *Total height of stacked tray:* An industrial engineer is requested to find an appropriate stacked height for the tray. The number obtained after the experiments is 6.5 inches. So, the team records this number as a design specification.

Cushion and Box:

The QFD of cushion and box indicates that the cushion thickness, percent utilisation of shipping space, and cushion density are the main focus. In addition, holding HSA in the vertical direction has to be included in the new packaging design. Before starting the design of the cushion and box, there is a need to ensure that weight and size of HSA packaging will not be changed during the design. This is because they can affect the way that the cushion and box are designed. Two factors are analysed for the new box and cushion designs, i.e. cushion density (1.0 and 1.8 lbs/ft^3) and cushion thickness (1.5 and 2.5 inches). Full factorial design of experiments is used [10]. The result shows that the proper condition for cushion density is 1.0 lbs/ft^3 and the cushion thickness is 2.5 inches.

Utilising Shipping Space:

After the specification of the cushion is obtained, the dimension of the box needs to be defined. The new box should have a percent pallet utilisation close to 100%. In the box, it contains an HSA package with the cushion's thickness of 2.5 inches. The box is designed to have a thicker cushion on the bottom and thinner cushion at the top. This is because we found that the bottom cushion is more critical to the HSA than the top one. With this concept, the shipping capacity per pallet is increased from 1,200 to 2,880 HSA. In the detailed design of packaging, computer software can be used to help shorten the development time. The output from the software can help select the design alternative with most utilised shipping pallet space (Fig. 10). The result from the software shows that the new packaging design can achieve the percent utilisation of shipping pallet at 99.54% (for area efficiency) and 89.24% (for cubic efficiency). This alternative has the highest percent utilisation compared with the other designs.

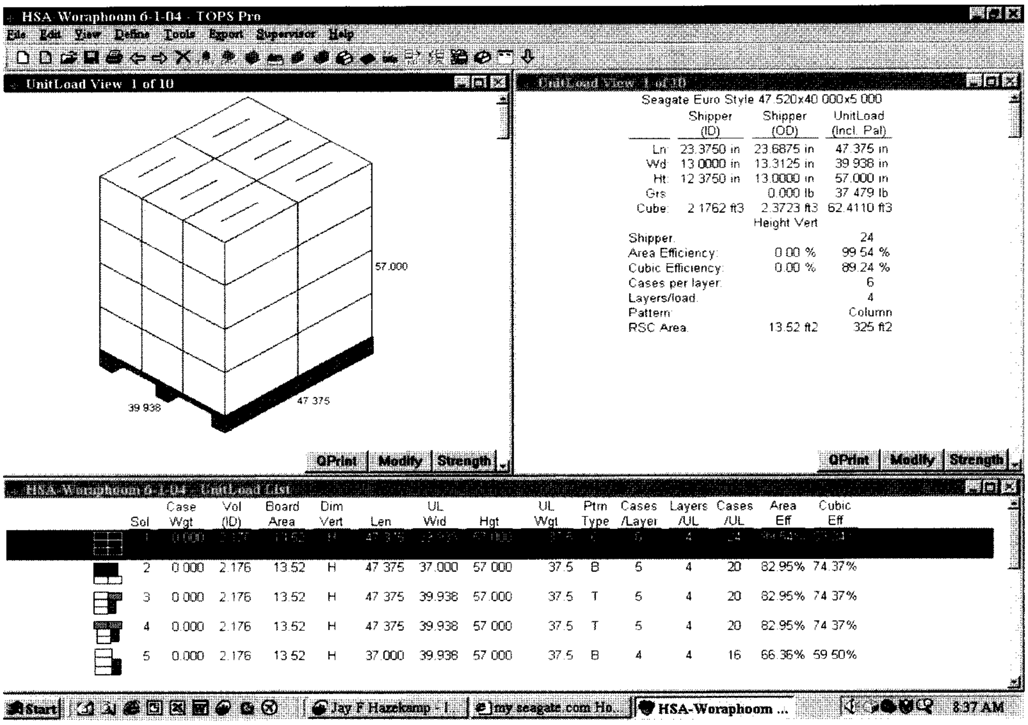
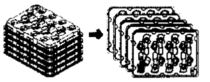
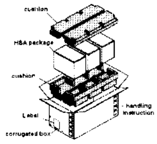
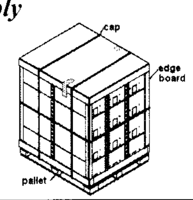


Figure 10: *Verify dimension with software*

Table 3: New concept packaging

Tray 	• Increased the number of cavities per tray from 6 to 8 cavities. • Tray profile is reduced. So, the number of stacked trays can be increased from 4 to 5 trays.
Box and Cushion 	• Weight of each HSA package is 1.69 kg. • Reduce top cushion thickness and increase the bottom cushion to maximise number of stacked boxes per pallet. • HSA is oriented vertically. • Total weight of box including HSA package is 6.27 kg which is not too heavy for operators.
Pallet Assembly 	• Utilise area on shipping pallet at 99.54%. • Have top and bottom cap to hold all boxes together during transport. • Attach warrantee tape to make sure that package is not disassembled before arriving at the customer warehouse. The capacity per pallet is 2,880 units.

When its components are combined together, the new packaging design concept for transport packaging can be summarised in Table 3.

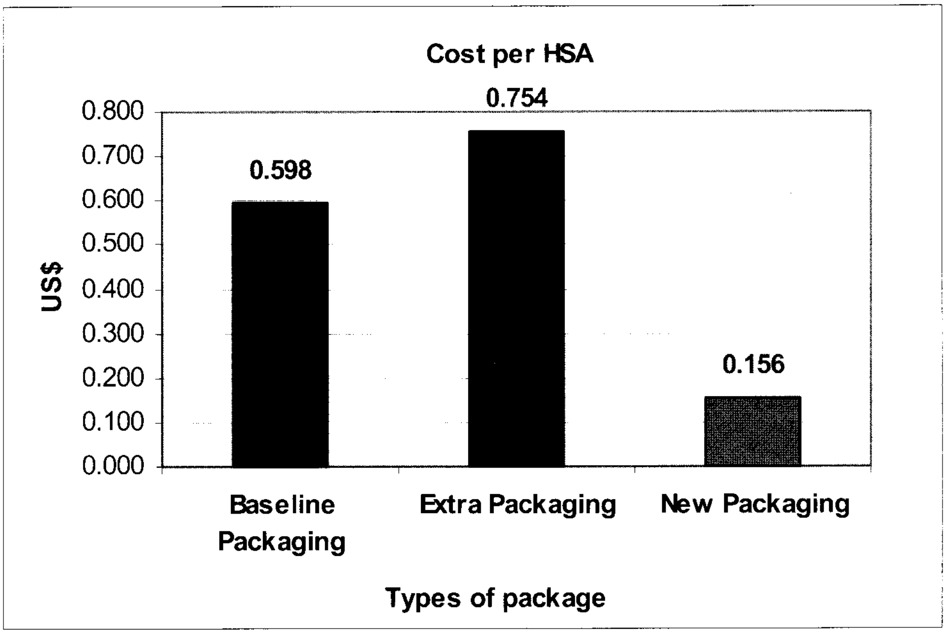
Verification Phase

The new packaging is tested with the normal packaging qualification. The condition of drop test is changed to mechanical handling test (ASTM D1083) which is more appropriate for transport packaging. The F-test analysis shows that the new design can reduce variation in gram-load difference significantly. As a result, it can be concluded that the new package performs better than the baseline. Hence, the new packaging design is qualified. Since the new package design can increase the number of HSA per pallet from 1,080 to 2,880, it is the breakthrough improvement. From Fig. 11, it can be seen that the new packaging has substantially less cost than baseline packaging and extra packaging.

Control Phase

To gain sustainable continuous improvement, all the specification in the QFD part-planning matrix is updated to reflect the changes. The specification is summarised as shown in Table 4.

Since the quality of each component has an effect on the packaging performance, it is recommended in Six-Sigma that KPIV(x) has to be controlled to maintain KPOV(y). As a result, statistical process control (SPC) is used to maintain the quality of the packaging components. It is found that the most important thing in the control phase is documentation that is well-written and easy to understand. The team documents all packaging instructions and specifications, and keeps them as references in a soft-copy format so that it can be published in the intranet of the company. For the documentation, it is approved by all authorised concerns before use, revised and updated constantly, and made available on-line anytime when needed. For the example, the QFD that is generated at the beginning of the study is filed and updated periodically.



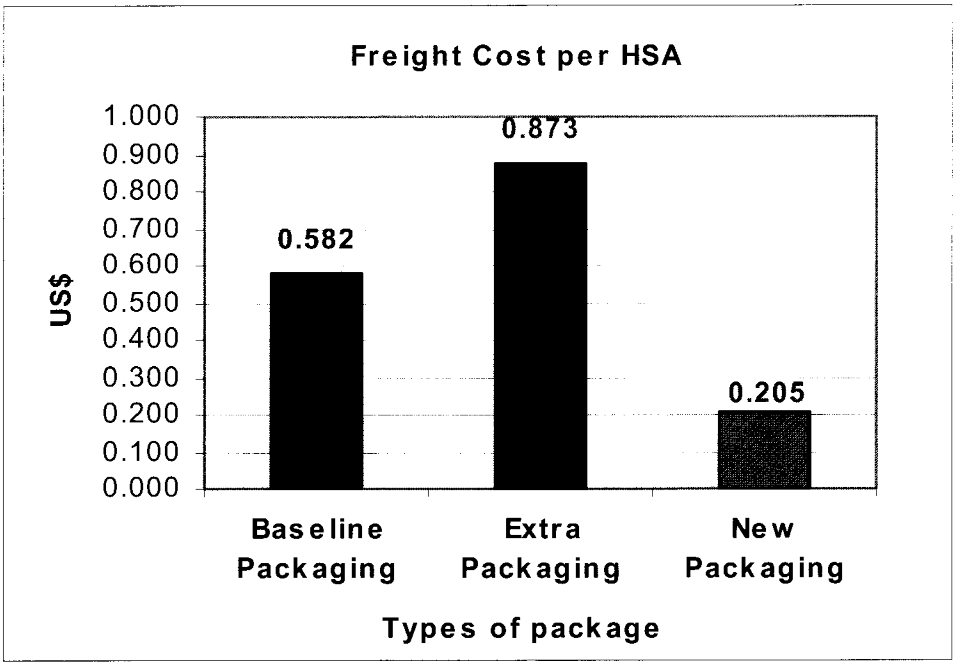


Figure 11: *Packaging cost and freight cost comparison*

Table 4: *Updated specification of tray, cushion, and box*

HOWs / Inputs → / WHATs / Outputs ↓	Tray										
	Liquid Particle count (LPC)	Out-gassing requirement	Surface resistivity	Has stacking feature	Total Height of stacked tray	Perimeter of tray (width)	Perimeter of tray (Length)	Quantity of HSA per tray	Weight of tray	Dimension not change after use or clean	Recycle material
Direction of Improvement	↓	↓	✖	✖	✖	✖	✖	↑	↓	✖	✖
Units	paritcle/cm2	ng/cm2	ohm.	Include	inch.	inch.	inch.	unit	kg.	%	Include
Target					6.5	8.3	11.3				Y
Lower Limit				Y	6.3	8.0	11.0	8			
Upper Limit	500	770	10^5		6.5	8.6	11.6		0.2	10	

HOWs / Inputs → / WHATs / Outputs ↓	Cushion									Box					
	Cushion density	Cushion thickness	Cushion Elongation	Dampening feature	Number of cushion parts	Weight of cushion	Dimension not change after use	Recycle material	Hold HSA in the vertical direction	No open gap on the box	Weight of box	% utilisation of Shipping space	Readable barcode & symbol	Dimension not change after use	Recycle material
Direction of Improvement	✖	✖	✖	✖	↓	↓	✖	✖	✖	✖	↓	↑	✖	✖	✖
Units	Lbs/ft3	inch.	%	Include	unit	kg.	%	Include	Include	kg.	kg.	%	Include	%	Include
Target	1.5	2.5	70	Y		1.0		Y	Y						Y
Lower Limit	1.35	2.63	63			0.9						80	Y		
Upper Limit	1.65	2.37	77		5	1.1	10			3	1			10	

6. Conclusion

Packaging design is the concern of many people both inside (staff in the organisation and supporting organisations) and outside (customers and suppliers) the company. In this study, the requirements of the main customer need to be cleanly understood. Once the voice of the customer is articulated, the trade-off of some requirements being critical to packaging design can be performed. However, both the working team and the customer can relax or even change them for mutual benefits. At the end, the team agrees to change the type of packaging from secondary packaging (group packaging) to tertiary packaging (transportation packaging). The design requirements can be translated to technical requirements with QFD. Software such as CAD, finite element analysis, and statistical analysis (MINITAB) make Six-Sigma processes much more simple and there are it is very useful for engineering analysis of new design concepts. Having designed the new packaging, prototype is validated to detect the problems that may be overlooked during the design process. In the control phase, documentation is very important. The team establishes the documents that are clear and easy to understand. They are revised and updated periodically.

After the packaging improvement project is achieved, the team shares the knowledge and best practices gained during conducting this study to another project. Feedback from those concerns can also help the team discover further improvement. It is interesting that the new packaging is useful for the raw material suppliers of HSA also. This is because their packaging is more expensive than our packaging. As a result, HSA asks its supplier to use our packaging for their products. This idea benefits our company a lot. This is because if we have the common packaging with our supplier, we can let them buy the prime packaging. And when we receive their packages, we can use them for shipping our finished products also. With this concept, the case study company can reduce packaging spending about 89% (66% from tray and 23% from carbon box) as stated in the define phase. In addition, the vendors agree to reduce their prices because they can reduce their transportation and handling costs. It is realised that newly designed packaging can help the company reduce the product cost very effectively.

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