# A Global Sourcing Strategy for Durable Tooling

by

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Submitted to the Sloan School of Management and the Department of Electrical Engineering and Computer Science in partial fulfillment of the Requirements of the Degrees of

**Master of Business Administration**
**Master of Science in Electrical Engineering & Computer Science**

In conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
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## ABSTRACT

Competitive pressures in manufacturing industries have led to an increased utilization of strategic sourcing initiatives: among them is low cost sourcing. While low cost sourcing has been used extensively for direct materials, the penetration of low cost sourcing in indirect materials is small. This thesis develops a global sourcing strategy for durable tooling and a methodology to help firms determine the best sourcing alternative for indirect materials. A low cost sourcing study done at Carrier compares the landed cost and quality of sheet metal stamping dies sourced from both China and the U.S. The study estimates that there is an opportunity to save 25-50% from low cost sourcing without compromising quality.

The sourcing strategy presents a framework for: 1) determining whether to source durable tooling locally, regionally or globally, and 2) for comparing the return (using total cost of ownership) and risk (country/regional) of sourcing alternatives. The primary deliverable of this research is a standard work process which integrates the durable tooling sourcing strategy into Carrier's current product development process. The product development process manages a product's lifecycle from concept to launch. The secondary deliverables, which are necessary to execute the durable tooling sourcing strategy, are: 1) sourcing decision matrix, 2) preferred tooling supplier database, 3) country selection framework, 4) lifecycle cost calculator, and 5) balanced tooling supplier scorecard.

The research leading to the development of the described sourcing strategy was conducted jointly between the MIT Leaders for Manufacturing Program and Carrier Corporation, a division of United Technologies.

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# 1. INTRODUCTION

Supply chains are the next source of competitive advantage.[1] This saying probably triggers ideas of the "make vs. buy" decision in the outsourcing process. However, this work deals with another type of strategic sourcing initiative: re-sourcing rather than outsourcing. Re-sourcing is the process of finding the best sourcing alternative given that a process or component is already outsourced. The objective of this thesis was to develop a global sourcing strategy for durable tooling and to make it a standard process.

The design and manufacture of durable tooling within Carrier is currently outsourced, therefore the durable tooling sourcing strategy deals with re-sourcing. There are three main points to the durable tooling sourcing strategy: 1) low cost sourcing, 2) increasing coordination, and 3) leveraging global scale. This thesis deals mostly with low cost sourcing because the benefits of increased coordination and economies of scale are obvious and there is likely to be little resistance in standardizing a process around them. In low cost sourcing, there are great benefits, but also great risks similar to those in outsourcing. In outsourcing there is a detailed analysis of what to outsource and what not to. It is crucial to understand the total cost of ownership of any strategic sourcing initiative whether it is outsourcing or re-sourcing. As a result, this work focuses a great deal of attention on quantifying the benefits and risks of low cost sourcing and provides a framework for analyzing the sourcing decision.

This chapter starts with an overview of Carrier Corporation and its parent company, United Technologies. Section 1.2 describes some of the issues that Carrier wants to address with a global sourcing strategy for durable tooling. Section 1.3 and 1.4 present the goals and deliverables of this thesis. Section 1.5 describes the approach and methodology used to develop the durable tooling sourcing strategy. Section 1.6 presents the benefits and risks of low cost sourcing and Section 1.7 provides an outline of the later chapters.

## 1.1 United Technologies and Carrier Overview

United Technologies (UTC) provides high technology products and services to the building systems and aerospace industries worldwide. Carrier, Otis and UTC Fire & Security make up UTC's building systems (commercial) portfolio, while Hamilton Sundstrand, Pratt & Whitney and Sikorsky comprise UTC's aerospace portfolio. Figure 1-1 shows 2005 revenues by business unit.

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[1] Fine, C. "Clockspeed." Perseus Books, 1998.

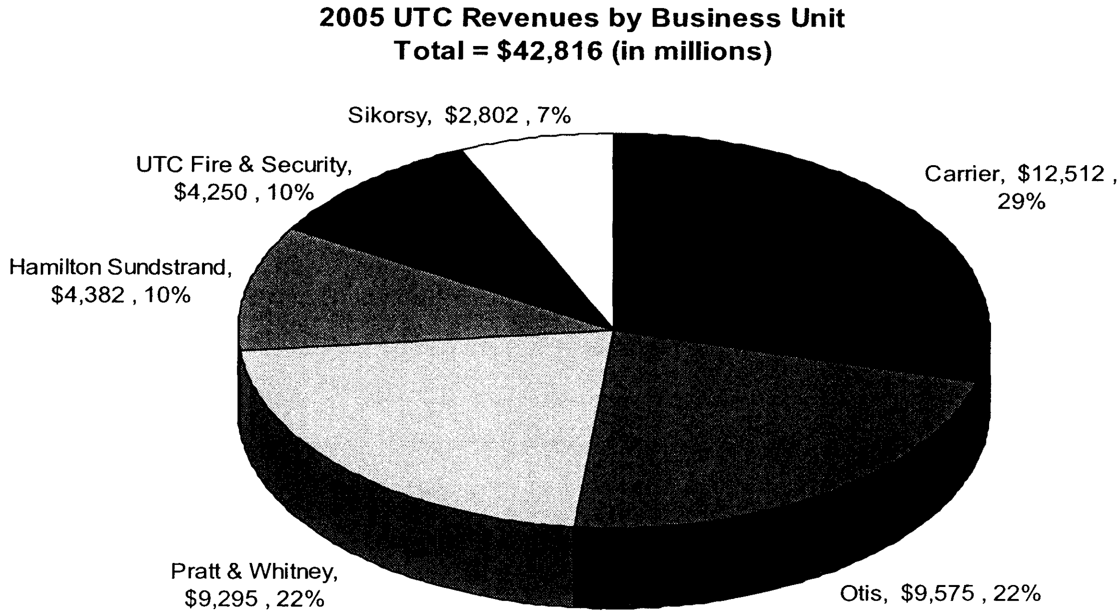


**Figure 1-1. 2005 UTC revenue by business unit.[2]**

Carrier is the world's largest manufacturer and distributor of heating ventilation and air conditioning (HVAC) systems, refrigeration and food service equipment, and related controls for residential, commercial, industrial and transportation applications. In addition, Carrier provides aftermarket services and components for the products it sells and those sold by other manufacturers in both the HVAC and refrigeration industries. It has four main business units (Light Commercial and Residential Systems, Refrigeration and Food Service Equipment, Transport Refrigeration, and Passenger Comfort) and more than seventy-five factories in over thirty countries. Each of the factories manufactures products in the regions it serves and approximately 55% of Carrier's revenues are generated outside the United States.

Carrier has historically grown both organically and through acquisitions; the Carrier footprint has increased dramatically in the last decade. In addition, productivity at Carrier, as at many other companies in the U.S, has been increasing year over year due to technological advances and improved business processes. Consequently, Carrier is able to run its business more efficiently with fewer resources, and although it has grown organically, Carrier has found itself with increasing spare capacity in its existing operations. This has led to significant factory consolidation in the last decade to reduce costs and remain competitive.

[2] United Technologies Corporation 2005 Annual Report, p 42.

In addition to consolidating factories, Carrier has also reduced complexity through product rationalization, and reduced cost through strategic and low cost sourcing of commodity products such as motors, valves, compressors, etc. and manufactured products that are components in air conditioning (A/C) units. In other words, Carrier's current strategy allows it to realize economies of scale in the commodity and manufactured products supply chains. However, Carrier does not have a strategy that leverages scale in the procurement of capital equipment, namely durable tooling (sheet metal and plastic dies, etc.), which is used to form/make the manufactured products (sheet metal frame components, injection molded fans, etc.) that are components of A/C units.

In 2004 and 2005 Carrier spent approximately $20 and $40 million respectively in durable tooling (sheet metal dies, plastic dies and reusable containers). Of the $60 million (approximately) that was spent on durable tooling in 2004/05, over $50 million was spent in high cost countries. Specifically, over $45 million was spent on durable tooling in the United States, where high labor rates lead to manufacturing costs that are among the highest in the world.

## 1.2 Problem Statement

Because it is decentralized, Carrier does not have a common strategy that deals with the procurement of durable tooling to leverage economies of scale in both design and build. There have been instances in which multiple factories, all producing the same product in different regions, have sourced the design and build of tooling separately, missing an opportunity to reduce costs through volume buying and incurring extra costs by paying for duplicate designs. Section 4.2 provides an example of this redundancy.

In addition, the product development process does not place enough emphasis on the sourcing of durable tooling, and as a result, sourcing is not very well integrated into the process. Consequently, the allowable lead time to deliver a tool is more compressed than it could be, often precluding some global suppliers from participating in the sourcing process. Potential costs savings are forfeited because a truncated lead time makes it more difficult to source from the global low cost supply base without incurring the exorbitant cost of expedited shipping. Therefore, Carrier must shorten the list of potential tooling suppliers to include only local or domestic suppliers, which makes the process less competitive. Carrier does not strategically utilize its global, regional or local supply chains to get the best combination of cost, quality and delivery. By shifting some of its durable tooling design and manufacturing to low cost regions, Carrier can reduce costs and maintain a competitive advantage. By establishing a capable supply base in emerging markets, Carrier will be much more likely to effectively serve those markets in the future.

## 1.3 Thesis Goal

The goal of the thesis research conducted at the Carrier Corporation World Headquarters in Farmington, CT was to develop a global sourcing strategy for durable tooling and integrate this strategy into the product development and capital expenditure processes. The durable tooling sourcing strategy has three main objectives.

The first objective is to ensure the appropriate use of low cost sourcing of durable tooling by taking advantage of Carrier's already established global supply base to minimize the total cost of ownership of durable tooling. The durable tooling sourcing strategy does not include finding and developing new suppliers in low cost regions as Carrier already has a capable and diverse tooling supply base.

The second objective is to increase the coordination between different investment sites to reduce the duplication of effort in the design and procurement of durable tooling. Already existing Platform (product) teams will facilitate the increased coordination between factories.

The third and final objective of the durable tooling sourcing strategy is to leverage Carrier's scale and scope in the procurement of durable tooling. Volume purchasing reduces the purchase price of durable tooling.

## 1.4 Deliverables

There are five main deliverables that Carrier received from this research. The first is a standard work document that incorporates the durable tooling sourcing strategy. The standard work is called the Durable Tooling Passport and is to be integrated into the current product development and capital appropriation processes. The second deliverable is a sourcing decision matrix which helps to determine if a particular tool is suitable for global, regional or local sourcing. The third is a preferred tooling supplier database which identifies Carrier's current tooling suppliers and indicates which factories have dealt with the particular supplier. In addition, there is a link to the supplier's performance (balanced supplier scorecard). The fourth is a total cost of ownership model (i.e. lifecycle cost calculator) for durable tooling which captures the lifecycle costs of durable tooling sourcing. The fifth is a balanced tooling supplier scorecard which evaluates suppliers on delivery, tool acceptance, quality and cost.

Deliverables two through five are embedded in the standard work process but merit discussion because they are the key decision making tools that drive the global sourcing strategy for durable tooling.

## 1.5 Approach and Methodology

A five step approach was used to develop the global sourcing strategy for durable tooling. The first step consisted of a literature review to determine the best practices in strategic sourcing for capital equipment and indirect materials. The next step was to conduct company wide interviews to understand the current sourcing process for durable tooling, internal best practices and potential challenges of low cost sourcing. Interviews were conducted with team members from manufacturing, supply management, finance, program management and quality. The third step was to identify the current spending patterns of Carrier factories to understand what Carrier was purchasing, when and with which suppliers. In addition, this step identified the capabilities of Carrier's current tooling suppliers. The fourth step was to analyze and document a durable tooling low cost sourcing initiative that one of Carrier's residential platforms was engaged in. The analysis was presented as a case study and compared the cost and quality of sourcing from China vs. sourcing from the U.S. The final step was to synthesize the information and develop a global sourcing strategy for durable tooling. This was an iterative process where the Supply Chain and Manufacturing departments provided feedback to help the shape the outcome of this research.

## 1.6 Low Cost Sourcing

Low cost sourcing is the practice of buying materials and services from suppliers in relatively underdeveloped countries with low wage rates mainly for the purpose of reducing costs. There are other benefits of low cost sourcing as well as significant risks which are outlined below.

**Benefits**

***Low cost.*** A significant cost savings opportunity of approximately 30%[3] exists, through taking advantage of the low labor rates in some regions.

***Twenty-four hour work day increases productivity.***[4] There is an opportunity to extend the effective work day by taking advantage of time zone differences. For example, when the work day in the United States is ending, it is only beginning in East Asia. By properly coordinating activities and meetings, operations can continue twenty-four hours a day.

***Presence in emerging markets.*** Most low cost regions are also emerging markets. Having a capable supply base in an emerging market is essential to entering that market when the conditions become appropriate.

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[3] Aberdeen Group, "Maximizing and Sustaining the Next Big Supply Savings Opportunity Low-Cost Country Sourcing Success Strategies," 2005.
[4] Friedman, Thomas L. "The World is Flat." Farrar, Straus and Giroux, 2005

***Encourage local suppliers to innovate.***[5] Globalization and low cost sourcing can encourage local suppliers to innovate and invest in new technology when they would otherwise be reluctant to do so, as it would cannibalize their existing technology and capital.

**Risks**

***Increased logistics costs and lead-time.***[6] All logistics costs increase (freight, duties, and port charges) due to low cost sourcing. Most low cost countries have underdeveloped infrastructure, which could lead to shipping delays. In addition, increased demand in low cost regions, especially China, is straining shipping capacity.

***Communication barriers.*** While some of the labor force in low cost regions of the world does have basic English speaking skills, the highly technical nature of designing, manufacturing and testing durable tooling can still lead to some communication difficulties.

***Resources required.*** More human resources are required in the Supply Management function to manage and execute a low cost sourcing initiative than to manage a local sourcing process.

***Low cost sourcing is a moving target.***[7] Low cost countries do not remain low cost forever. Increased exports put upward pressure on wages and currency value.

## 1.7 Thesis Overview

Chapter 2 defines durable tooling and the need for a global sourcing strategy for durable tooling. It then explains the data collection methodology and summarizes the findings in terms of: 1) type of capital expenditure, 2) high cost vs. low cost region expenditure and 3) capital expenditure by region. This chapter also shows that approximately 80% of tooling is purchased for a new product development. Durable tooling, mainly sheet metal and plastic injection molding dies, make up a significant portion of Carrier's entire capital expenditures. Finally, over 87.5% of Carrier's durable tooling expenditure is sourced from high cost regions. As a result, there is an opportunity to reduce costs through low cost sourcing.

Chapter 3 outlines a durable tooling low cost sourcing initiative pursued by a residential air conditioner platform (product development team). The results of the study show that savings of between 20- 45% are possible from sourcing a sheet metal stamping die from China rather than the U.S. In addition, quality of the work performed by the Chinese supplier is competitive to that of the U.S. suppliers in the study.

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[5] Closs, David J. "Logistics Perspectives on Low Cost Sourcing." Logistics Quarterly Volume 10 Issue 4, November 2004

[6] Aberdeen Group, "Maximizing and Sustaining the Next Big Supply Savings Opportunity Low-Cost Country Sourcing Success Strategies", 2005.

[7] Ibid.

Chapter 4 discusses the global sourcing strategy for durable tooling and its three main objectives: 1) low cost sourcing, 2) increasing coordination and 3) leveraging global scale. In addition, this chapter gives a snapshot of the standard work document (the main deliverable for this internship) as well as the remaining deliverables: 1) sourcing decision matrix, 2) preferred tooling supplier list, 3) country selection framework, 4) lifecycle cost calculator and 5) balanced tooling supplier scorecard.

Chapter 5 addresses the organizational challenges that must be overcome in order for this project to be successful in the long term. It evaluates Carrier through three perspectives on organizational analysis: 1) strategic design lens, 2) political lens and 3) cultural lens. From a strategic design perspective, Carrier has the processes and teams in place in order for this project to be successful. Culturally, some of the prevailing attitudes and beliefs about the quality and difficulty of low cost sourcing can be an impediment to the success of this project and need to be managed.

Chapter 6 draws both general conclusions from this research study and provides recommendations for Carrier, and other firms that may be involved in low cost sourcing initiatives for indirect materials such as capital equipment. Low cost sourcing can lead to significant savings if utilized properly or major costs if used improperly. Not every tool is a candidate for low cost sourcing; this decision depends on the supplier capability and the lead time and complexity of the tool. This chapter also outlines areas for future consideration.

Appendix I contains a document called "Overview Recommendations for Measurement System Analyses and Machine Capability Analyses for Coils Shop Equipment." This document outlines the machine/tooling qualification process used by a Global Manufacturing and Quality Program Manager to qualify all coil shop machines and tooling. This document should serve as a guide for the qualification of all tooling and hopefully lead to a tooling qualification standard in the future.

Appendix II contains the country statistics used to generate the rankings in the country selection framework discussed in Section 4.4.3.

# 2. Background

This thesis is the culmination of a joint endeavor between Carrier Corporation and the Leaders for Manufacturing Program. The objective of this effort was to develop a global sourcing strategy for durable tooling that would guide Carrier's product development and manufacturing teams. It is important to note that this project is concerned with re-sourcing rather than outsourcing of durable tooling.

Section 2.1 provides a brief explanation of what tooling is. Section 2.2 explains why there is a need for a global sourcing strategy for durable tooling at both a tactical and strategic level. Section 2.3 outlines the data collection methodology used to capture the current tooling spend. Section 2.4 presents the results of the collected capital expenditure data in three different ways: by type of capital expenditure, by commodity, and by region – developed (high cost) vs. undeveloped (low cost) supply markets. This section makes the case for low cost sourcing due to the following reasons: 1) the design and manufacturing of durable tooling is labor intensive, 2) low cost countries can offer significant labor savings, and 3) most of Carrier's durable tooling is sourced from high cost regions.

## 2.1 Tooling Overview

**Tooling** is equipment used to mold, trim and form materials into a desired shape (e.g. sheet stamping dies for producing the sheet metal top cover of an air conditioner). Tooling can be divided into two groups: durable tooling and perishable tooling. As the name suggests, **durable tools** have a long lifespan. For example, a *sheet metal stamping die* may only have to be repaired or replaced a few times in the entire life cycle of the product for which it was made. **Perishable tools,** on the other hand, have a much shorter lifespan. For example, *punches* (used to punch holes in sheet metal) or cutting tools may need to be replaced or sharpened on a weekly basis.

Perishable tooling is usually kept in stock and replenished periodically, while durable tooling is rarely ever kept in stock because it represents such a large capital expenditure. Figure 2-1 shows examples of sheet metal stamping (left) and plastic injection molding dies (right).

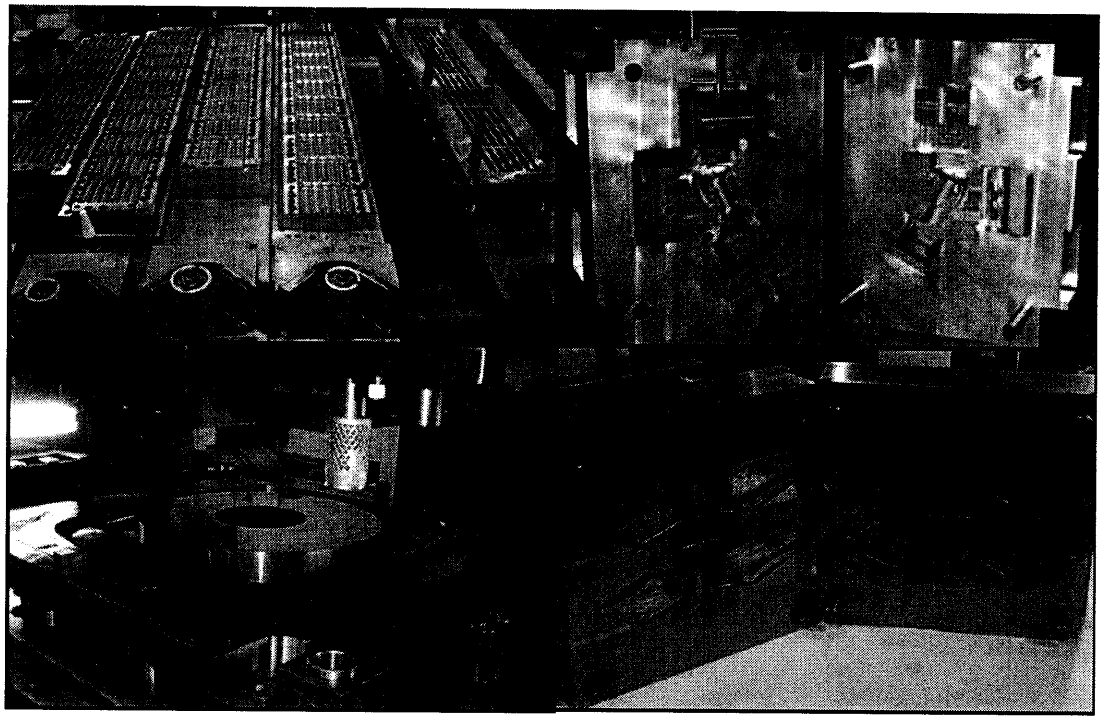

**Figure 2-1. Durable tooling – sheet metal stamping (left) and plastic injection molding dies (right).**

## 2.2 Benefits of a durable tooling sourcing strategy

Carrier has strategies in place for sourcing most direct materials that represent true variable costs. Some examples of direct materials include: 1) commodities – motors, valves, compressors, control and electronics, fans and blowers, etc. and 2) manufactured products – plastic injection molded parts (fan blades), sheet metal stamped parts, copper tubing fabrications, etc.

Strategic Global Sourcing (SGS) is the group within Carrier that is responsible for sourcing commodities and manufactured products for all business units. This initiative has resulted in cost savings of 10-30% on commodity products.[8] For capital equipment such as durable tooling and industrial equipment (on which Carrier spent $155M in 2004-05), no such sourcing strategy is in place.[9]

A coherent sourcing strategy for durable tooling and industrial equipment has the potential to create substantial cost savings relative to the current ad hoc process. However, in order to determine whether such a strategy would indeed be successful, we must first establish the size of the potential benefit and examine the purchasing patterns and volume requirements for both equipment categories.

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[8] "Carrier Global Sourcing Guidebook," version 1.0, June 2005.
[9] Examples of durable tooling include sheet metal stamping dies, plastic injection molding dies, reusable containers, etc. Examples of industrial equipment include assembly equipment, leak test systems, stamping presses, paint equipment, etc.

While durable tooling and industrial equipment each represent significant fixed costs in the production of air conditioning systems, the life expectancy, and thus the timing of purchase of each is quite different. Durable tooling is always purchased at the beginning of a new product launch and over the life of the product for process or product changes, repairs, etc. For example, a sheet metal die, used in the production of one part, may only need to be replaced or repaired a few times over the life of a given product (e.g. A/C). On the other hand, a stamping press, used to form many different parts for many different product families over many generations, is only purchased to replace older presses or to expand capacity. A stamping press is not purchased every time a new product is launched.

Figure 2-2 illustrates the relationship between the volume and complexity of different products and potential cost savings that could result from an efficient sourcing strategy. Because durable tooling is purchased more frequently and in higher volume than industrial equipment, strategic sourcing of durable tooling should allow Carrier to realize economies of scale and, thus, greater potential cost savings. In addition, the design and manufacture of durable tooling is less complex relative to that of industrial equipment and, accordingly, requires less time and labor. There are typically more suppliers for durable tooling than for industrial equipment. As a result, the sourcing of industrial equipment is usually a more difficult and time intensive process.

At present, the development of a sourcing strategy for durable tooling is the first priority given the significant potential for cost savings and relative ease of implementation in this area relative to that of industrial equipment. That being said, the strategic sourcing of industrial equipment can also provide significant benefits and should be explored in the future.

There are strategic reasons in addition to tactical reasons for Carrier having a global sourcing strategy for durable tooling. There is a low cost sourcing component to the sourcing strategy which has high strategic importance not only within Carrier, but also with the rest of UTC. Low cost sourcing can help to establish a supply base for tooling in low cost regions which will give Carrier a competitive advantage in the future when market opportunities open up as those regions develop. In addition, the rest of UTC will have access to a developed global supply base for their tooling needs. Finally, have a global tooling supply base will help to meet UTC's offset (foreign investment) requirements. A more detailed explanation of these three strategic implications follows.

***Future Market Opportunity:*** Carrier would like to have a developed supply base in emerging regions because emerging markets represent a huge market opportunity in the future for all of UTC. When emerging markets become more than just marginal consumers for UTC's commercial and aerospace products, UTC will have an established presence in those regions and will be able to enter the market.

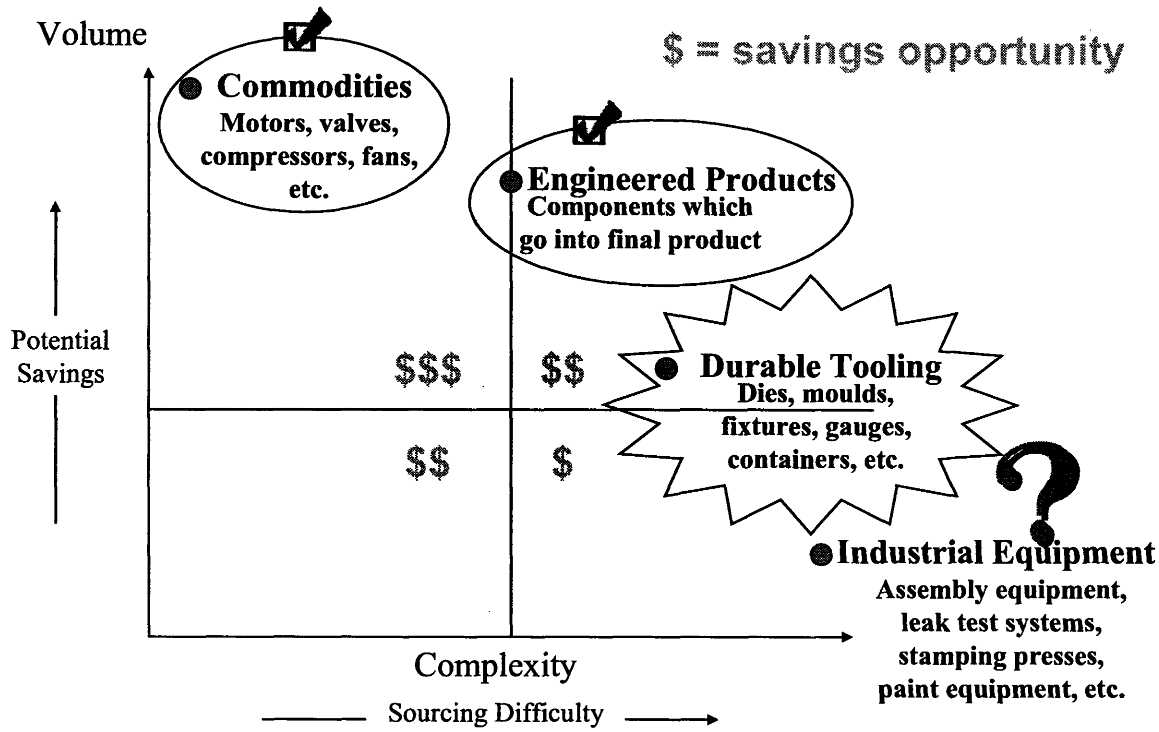


**Figure 2-2. The product volume vs. product complexity is used to determine the potential for cost savings from strategic sourcing.**

***Global Supply Base for all of UTC to leverage:*** Carrier would like to pave the way into low cost sourcing of durable tooling for some of UTC's aerospace businesses. The aerospace businesses accounted for over 55% of UTC's capital expenditures in 2005 (see Figure 2-3 below). Pratt & Whitney, Hamilton Sundstrand and Sikorsky have only very limited experience with low cost sourcing because much of the work for the aerospace business is comprised of US military contracts. Since security concerns associated with these projects make it impossible to source from other countries for many components, very little work has been eligible for low cost sourcing in the past. In the future, some of the sourcing restrictions imposed by the government will be eased slightly, and UTC would like to have a global supply base from which to choose. Carrier will be able to provide low cost sourcing assistance and supplier contacts for durable tooling to the rest of UTC.

***Offset Requirements:*** When UTC's aerospace businesses sell their products (aircraft engines, helicopters, etc.) to foreign governments, those governments require the firms to reinvest a certain amount of the resulting income back into the country in some form. This practice is called **Offset**. For example, when Sikorsky sold helicopters to Turkey, they were required to reinvest a portion of the proceeds from that sale into Turkey. Sourcing durable tooling from a Turkish supplier would be one way to achieve this. More importantly, any UTC company can provide this investment to meet the offset requirement. Carrier's global presence can facilitate this by either sourcing durable tooling from Turkey for a Carrier project or providing supplier contacts to the other UTC business units.

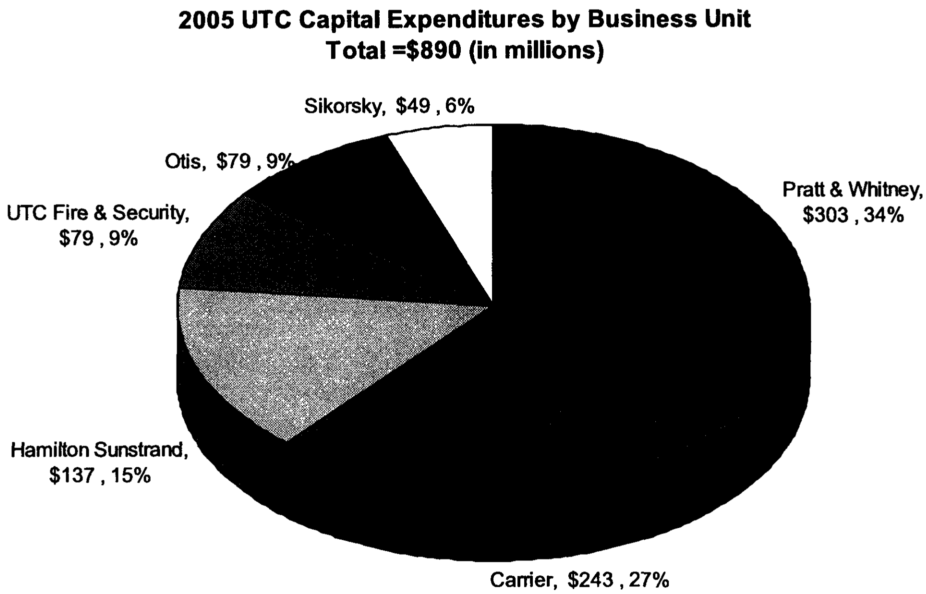


**Figure 2-3. 2005 capital expenditures by business unit.**[10]

## 2.3 Data Collection Methodology

The first step in developing a global sourcing strategy is to understand the internal spend.[11] Therefore durable tooling and industrial equipment capital expenditure data was collected from thirty-five Carrier factories, representing more than 85% of total capital expenditures. A template spreadsheet was sent to each factory. Each line item in the template was classified by commodity type, expenditure type, platform (product line), manufacture cost, supplier name, supplier location, new or sustaining expenditure, weight (mostly relevant for tooling) and the year that the expenditure was made. The template that each factory populated is shown in Figure 2-5. Figure 2-5 shows the worldwide locations all Carrier's factories and Design centers. The bottom right table in Figure 2-5 shows that only 24 factories had durable tooling expenditure in 2004 and 2005.

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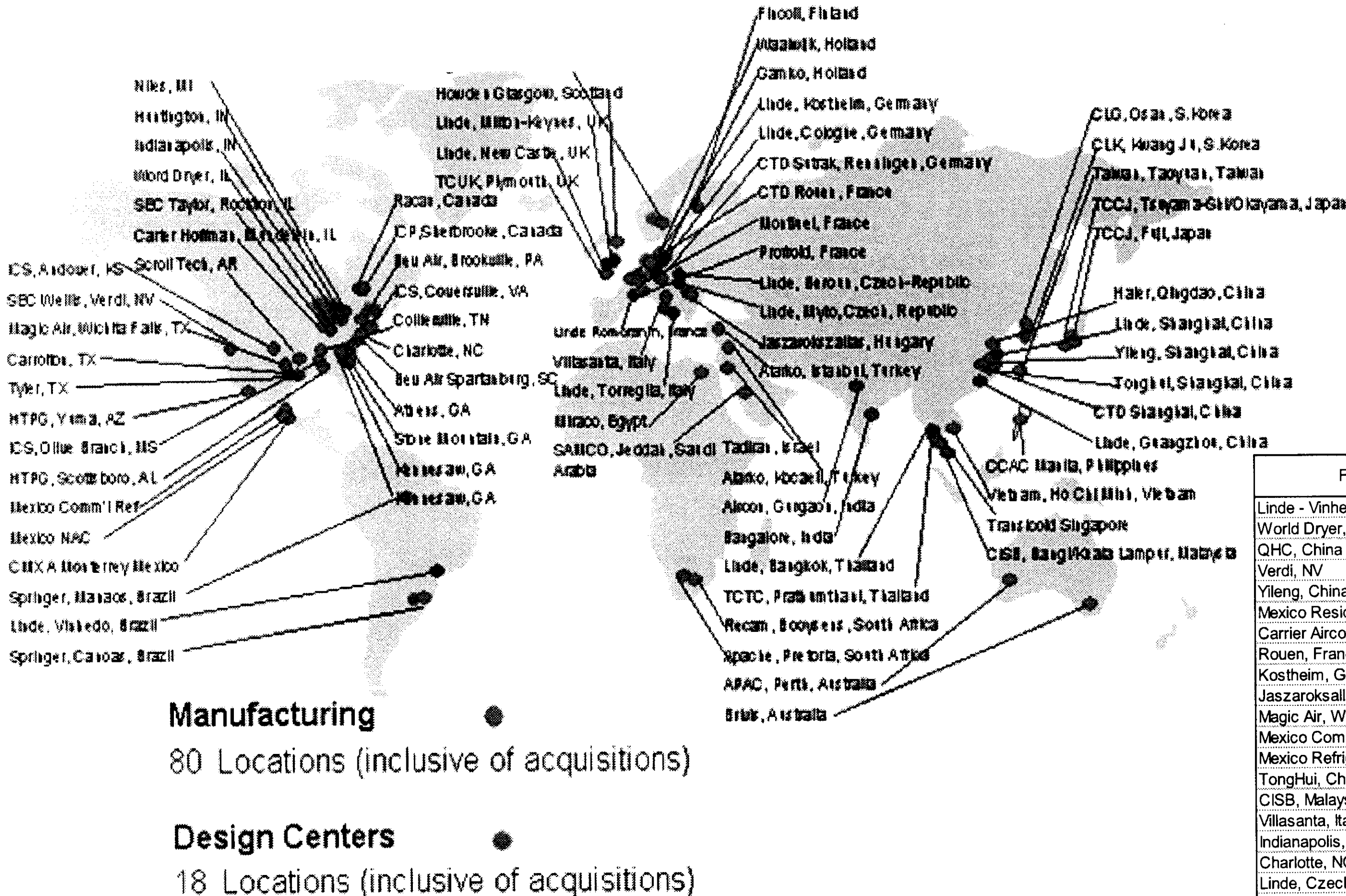
[10] United Technologies Corporation 2005 Annual Report, p 72.
[11] Nelson, David R."Low Cost Country Strategic Sourcing," 90th Annual Supply Management Conference, 2005.

| Factory | Commodity | Type | Platform | Make Cost (USD '000 @05PFX) | Make Supplier Name | Make Supplier Location | New or Sustaining | Weight | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Sheet metal dies | Cost Reduction/Productivity | Everest | | | | New | <100# | |
| | Plastic dies | EH&S | Starfire | | | | Sustaining | (100#, 500#) | |
| | Other tooling | Information Technology | Global console | | | | | >500# | |
| | Reusable containers | Capacity Expansion | Centurion | | | | | | |
| | Kitting/Kanban equipment | New Product | Global bottle cooler | | | | | | |
| | Presses | New Production of Existing Products | Thunderbolt | | | | | | |
| | Braze equipment | Engineering Test Equipment | Commercial Applied (Hydronic Systems) | | | | | | |
| | Leak test | Leasehold improvements | Residential Ducted | | | | | | |
| | Run test | Other | Commercial Packaged (DX Systems) | | | | | | |
| | Paint equipment | Quality | DFS/WRAC | | | | | | |
| | Assembly line | Replacement / Maintenance | Truck/Trailer | | | | | | |
| | Other machine | Restructuring | Container | | | | | | |
| | EH&S equipment | | Bus/Rail | | | | | | |
| | | | Commercial Refrigeration | | | | | | |
| | | | Food & Beverage Retail Display | | | | | | |
| | | | Food Service | | | | | | |
| | | | Controls | | | | | | |
| | | | Compression | | | | | | |
| | | | Other | | | | | | |

<100# - less than 100 lbs.
(100#, 500#) - between 100 and 500 lbs.
>500# - greater than 500 lbs.

**Figure 2-4. Capital expenditure template used by selected factories to report durable tooling and industrial equipment expenditures.**

NOTE: The entries in the Commodity, Type, and Platform columns were restricted to elements seen in the chart above as these are the major categories that the Financial Planning and Analysis (FPA) Department uses to classify capital expenditures. The entries in the Commodity field are either durable tooling or industrial equipment. The entries in the Type field are the type of expenditure (new product, environmental health and safety (EH&S), cost reduction, etc.). Platform refers to either a product line (Everest – residential air conditioner product line, Starfire – commercial chiller), a type of air conditioner (WRAC = window room A/C), or type of product (Commercial Refrigeration, Food Service, Food & Beverage Display, Truck/Trailer A/C).




| Factory | Durable Tooling Spend ($000's) |
|---|---|
| Linde - Vinhedo, Brazil | 14 |
| World Dryer, Berkeley, IL | 17 |
| QHC, China | 23 |
| Verdi, NV | 26 |
| Yileng, China | 45 |
| Mexico Residential | 49 |
| Carrier Aircon Ltd. | 54 |
| Rouen, France | 58 |
| Kostheim, Germany | 63 |
| Jaszaroksallaz, Hungary | 102 |
| Magic Air, Wichita Falls, TX | 124 |
| Mexico Commercial | 160 |
| Mexico Refrigeration | 195 |
| TongHui, China | 284 |
| CISB, Malaysia | 524 |
| Villasanta, Italy | 757 |
| Indianapolis, IN | 1,181 |
| Charlotte, NC | 1,400 |
| Linde, Czech Republic | 1,719 |
| Athens, GA | 1,734 |
| Kwang Ju, Korea (CLK) | 2,623 |
| Thailand (TCTC) | 3,123 |
| Tyler, TX | 8,705 |
| Collierville, TN | 34,537 |
| Grand Total | 57,519 |

**Figure 2-5. Carrier worldwide factory locations and the 24 out of 35 factories involved in the study that had durable tooling expenditures.**[12]

[12] Illustration taken from a Carrier presentation – Durable Tooling Strategy: History and Future.

## 2.4 Summary of Results

The 2004-2005 capital expenditure (industrial equipment and durable tooling) for the 35 Carrier factories involved in the study was $155 million, 70% of which came from new product introductions. Figure 2-6 shows the top five capital expenditures by type for 2004-2005. Note that the top five expenditures account for over 96% of the $155 million spent in industrial equipment and durable tooling.

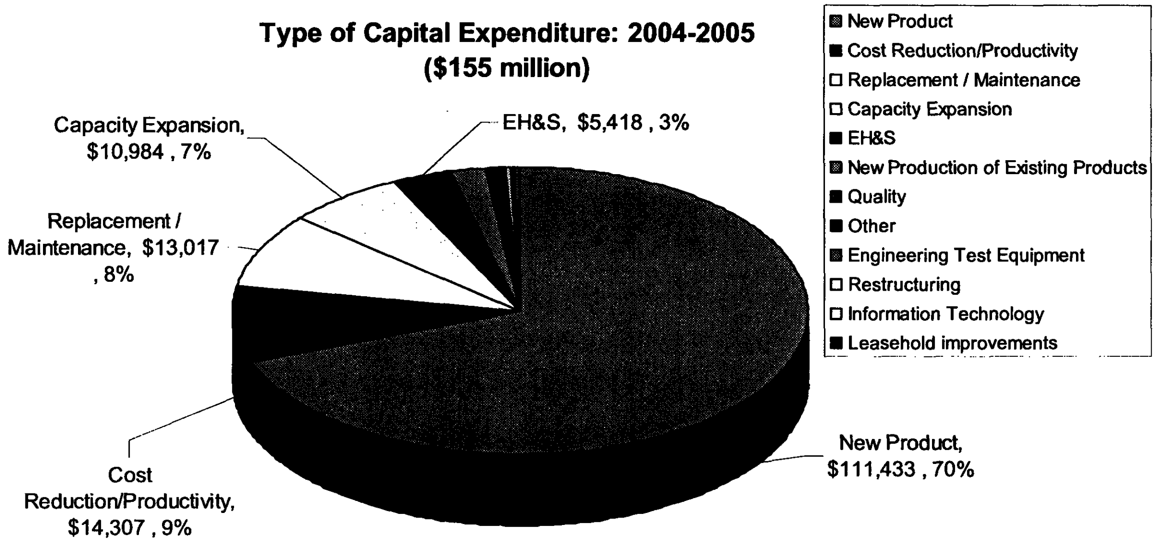



**Figure 2-6. Capital expenditure by type for 2004-2005. The top five items account for over 96% of the total capital expenditure in the time period.**

For reasons discussed in Section 2.2, this study focuses on durable tooling only. Figure 2-7 presents the 2004-2005 durable tooling expenditure of approximately $58 million by type. It is interesting to note that new product introductions also account for the majority of money spent in durable tooling, 80% of the total. Cost reduction and productivity improvements represent 14% of the total while new production of existing products, replacement/maintenance and environmental health and safety (EH&S) make up the remaining 6%.

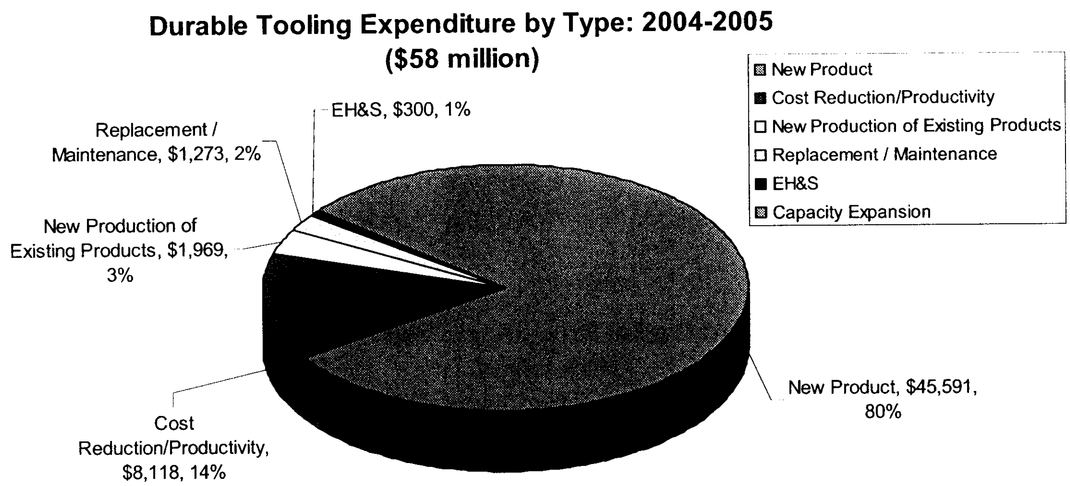



**Figure 2-7. Durable tooling expenditure by type for 2004-2005.**

Figure 2-6 and Figure 2-7 indicate that approximately 70% of all capital and 80% of durable tooling expenditures are incurred for new product development and launch. Figure 2-8 illustrates the mix of industrial equipment and durable tooling that were procured over 2004-2005. Sheet metal and plastic dies, other machines and tooling, presses, assembly lines, paint equipment and reusable containers represent over 85% the total capital spend.

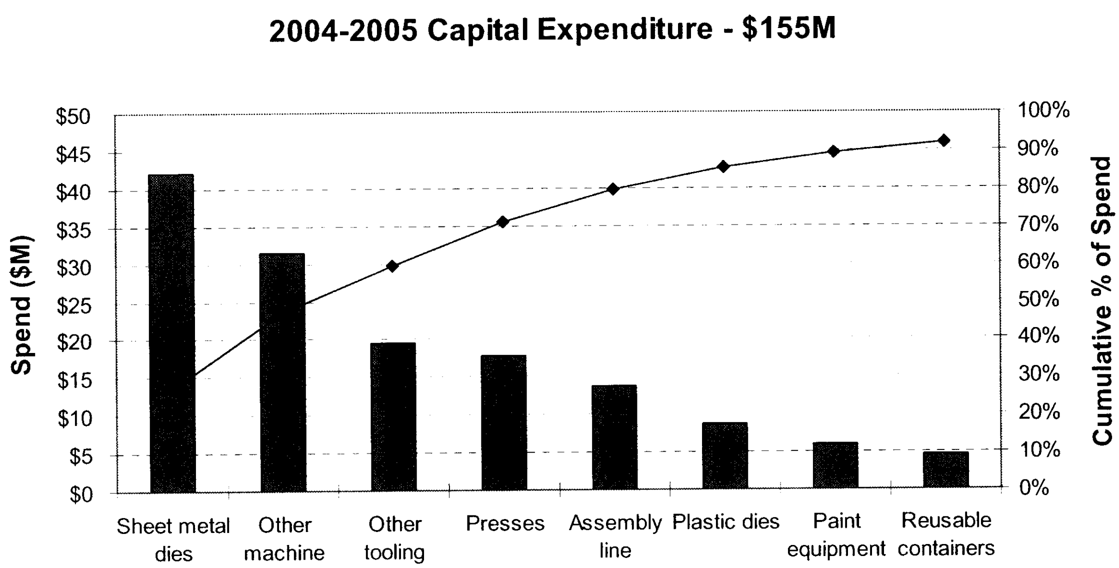



**Figure 2-8. Pareto chart of industrial equipment and durable tooling spend for 2004 and 2005.**

While this study only focuses on durable tooling it is nonetheless interesting to understand the total mix of purchases because it reinforces the decision to focus on tooling: durable tooling is a significant portion of the total expenditure.

However, it is interesting to note that the Everest program in the residential and light commercial systems business unit accounted for a significant portion of the expenditure in all four categories because manufacturing capacity was added to handle higher volumes. The Everest program accounted for over 63% of the total capital expenditure and over 62% of the durable tooling expenditure. While it is uncommon that one project is responsible for so much of the capital spend, the results are still representative of Carrier on an aggregate level.

### 2.4.1 High Cost Sourcing vs. Low Cost Sourcing

As stated earlier, Carrier spent $55 million on durable tooling (reusable containers, sheet metal, and plastic injection molding dies) in 2004-2005. Of the $55 million, approximately 87%, or $48 million, of that was sourced from high cost regions (Figure 2-9).

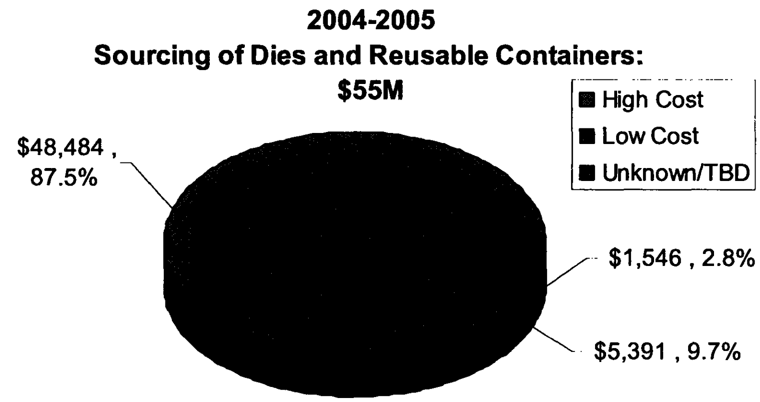



**Figure 2-9. 2004 and 2005 spend data by region.**

What is a high cost region? To answer the opposite question: a low cost region (for durable tooling) is defined as one with labor rate less than or equal to 30% of the US labor rate. The choice of the 30% threshold is somewhat arbitrary, but one reason for it is that there is a significant labor difference between Taiwan and Singapore (26%) which clearly divides the graph in Figure 2-11 into two groups of countries. In addition, within Carrier, Singapore is no longer viewed as a low cost country while Taiwan is. According to Figure 2-11, Singapore's labor rate is approximately 53% of the US labor rate and Taiwan's is 27%. Therefore it is convenient to set the low cost source threshold at 30% of the US wage rate because it is sufficiently lower than Singapore's labor rate. Also, using 30% does not make Singapore a borderline case. In Figure 2-11, every country to the right of Taiwan is high cost.

Labor rate is used as the key determinant of whether a country is low cost because it makes up a significant part of the total cost of most durable tooling. The design and manufacture of durable tooling is highly labor intensive: over 55% of the cost of a sheet metal stamping (fin[13]) die is labor (see Figure 2-10). Also note that shipping costs (expedited shipping in this case) and customs costs are a relatively small portion of the total cost.

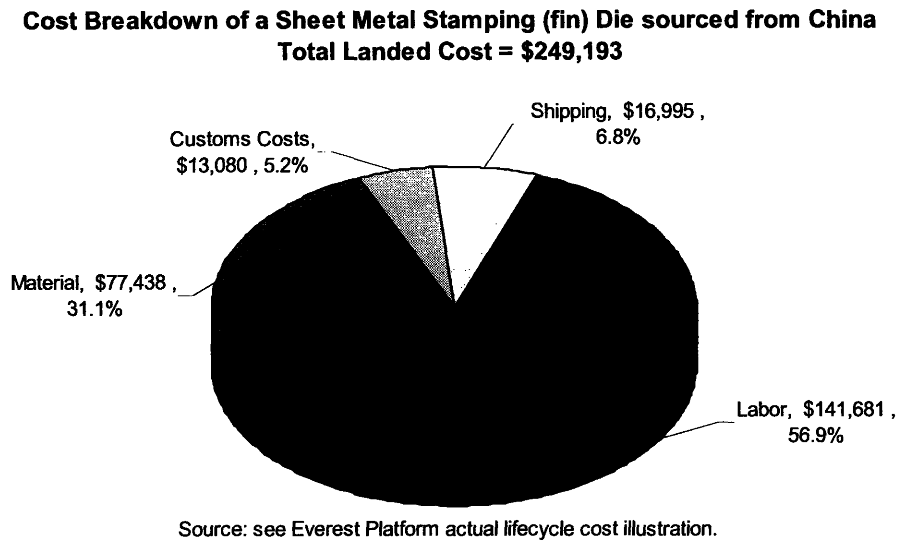



**Figure 2-10. Cost breakdown of a typical sheet metal stamping die.**

However, in practice, just because a country has a significant wage advantage does not mean that it can offer significant cost savings; labor in low cost countries is typically less skilled and less productive. However, all else equal, there can be huge opportunity to reduce costs through low cost sourcing.

Figure 2-12 shows the 2004 and 2005 durable tooling expenditure by region. The red (darkly shaded) bubbles represent durable tooling sourced from high cost countries and the green (lightly shaded) bubbles represent durable tooling sourced from low cost countries. The sizes of the bubbles indicate the relative magnitude of the expenditure. Carrier spent approximately $45 million, or 82% of its total durable tooling expenditure for 2004 and 2005, in the U.S.

As stated earlier, the Everest program was responsible for a significant portion of Carrier's capital expenditure in 2004-05: approximately $34.5 million of the $55 million durable tooling expenditure was due to the Everest program in the Residential and Light Commercial A/C business unit which sourced most[14] of its durable tooling from the US.

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[13] Fins are very thin sheet metal strips that make up the heat exchanger of an air conditioner. See Figure 3-1.

[14] Five sheet metal stamping (fin) dies were procured from a Chinese supplier.

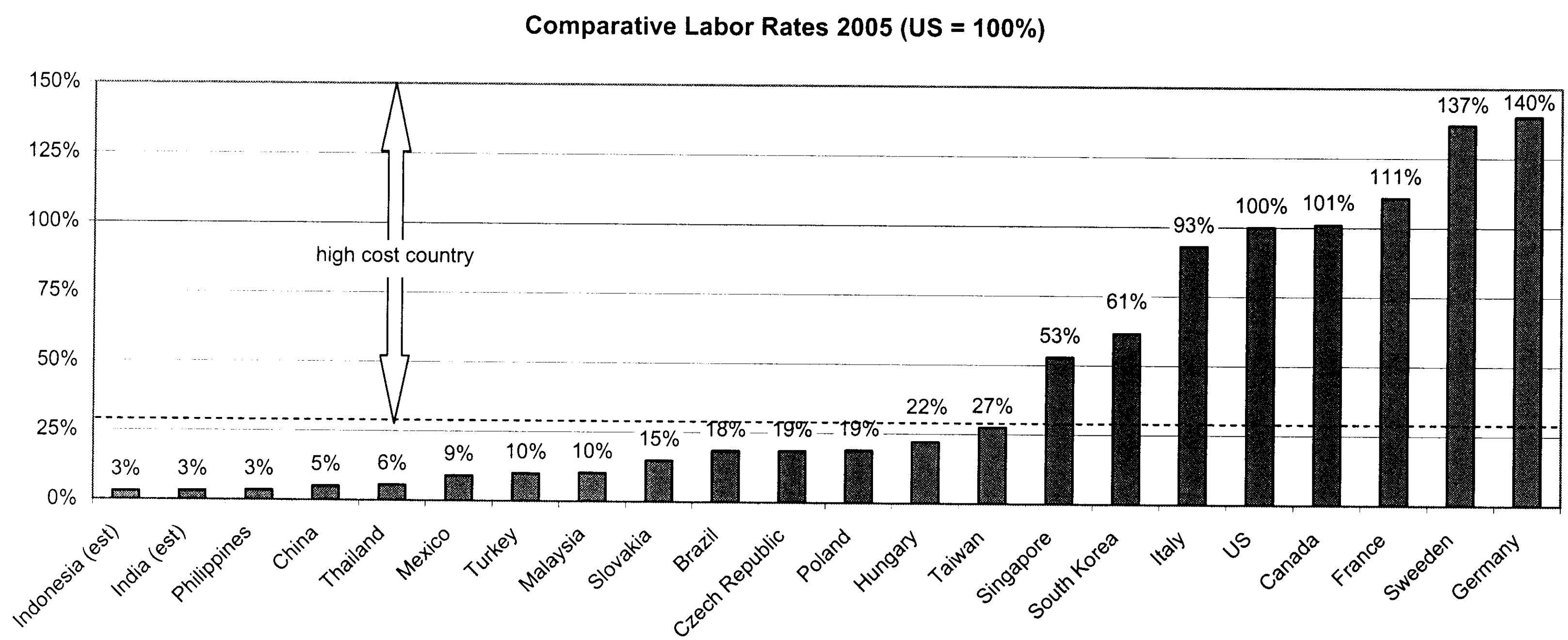


**Figure 2-11. Comparative labor rates for countries that Carrier sources durable tooling from.[15]**

[15] Wage information obtained from the Economist Intelligence Unit Country Reports, 2005.

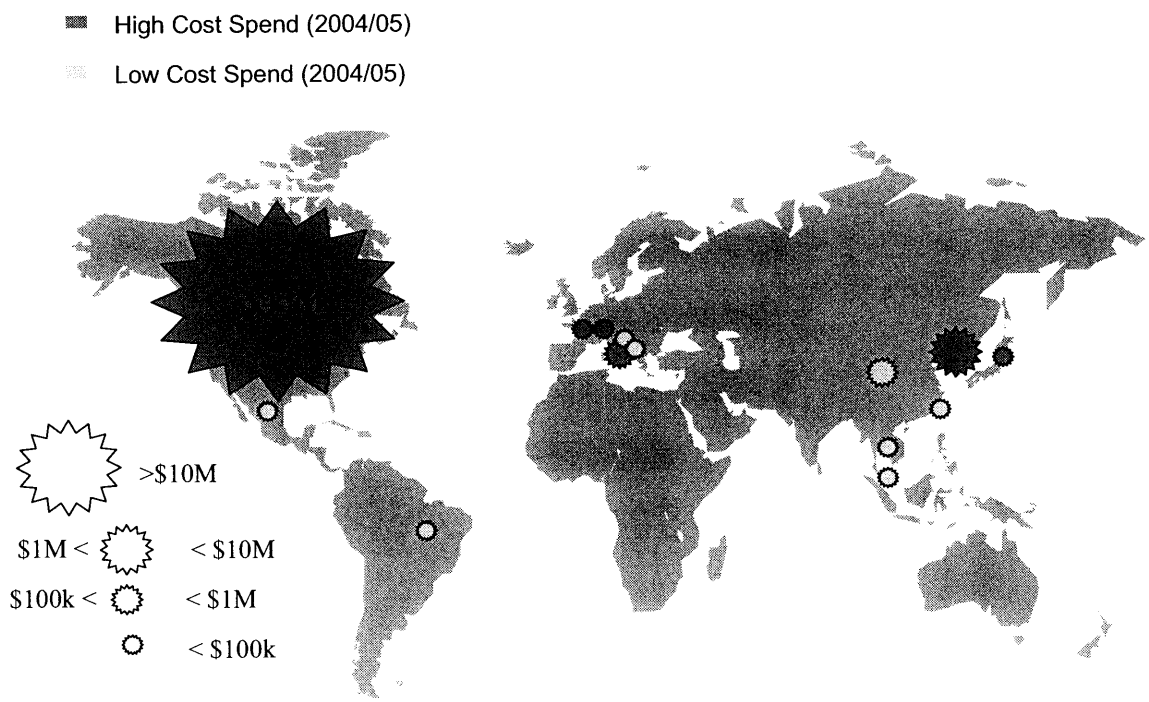


**Figure 2-12. Durable tooling expenditure by region for 2004-2005.**

The U.S. is one of the highest (wage) cost countries from which Carrier procures durable tooling (see Figure 2-11). The rest of the high cost countries in Figure 2-11 include France, Germany, Italy, South Korea and Japan. Mexico, Brazil, Czech Republic, Hungary, China, Malaysia, Taiwan and Thailand make up the low cost countries in Figure 2-11.

## 2.5 Chapter Summary

Chapter 2 dissected Carrier's 2004 and 2005 capital expenditure data in many ways. The key findings included; 1) new product development accounts for over 80% of durable tooling expenditures, 2) durable tools (sheet metal stamping and plastic injection molding dies) are a significant portion of the capital budget, and 3) Carrier procures over 87% of its durable tooling from high cost countries. In addition, this chapter defined a classification system for countries: those that had labor rates less than or equal to 30% of US labor rates are called low cost countries; all others were referred to as high cost countries. Chapter 2 set the stage to explore low cost sourcing; Chapter 3 will provide an example from a Carrier new product development cycle.

# 3. DURABLE TOOLING CASE STUDY: LOW COST SOURCING FROM CHINA

It is often a good idea to test new initiatives on a small scale: this helps to quantify both the benefits and risks and can help to determine larger scale feasibility. Carrier had the opportunity to test low cost sourcing during the Everest Program (residential air conditioner product line) and compare it directly to local sourcing. Chapter 3 investigates the low cost sourcing initiative. Sections 3.2 and 3.3 provide cost comparisons between low cost sourcing and local/domestic sourcing. Section 3.4 compares the quality of the two new initiatives.

## 3.1 Low Cost Sourcing: Fin Dies

A small percentage of the durable tooling for the Everest program was purchased from a Chinese supplier: five sheet metal stamping dies – fin dies. Sourcing from China was possible in this case because the product development team started prototyping the fins and associated tooling early in the product development process. As a result, the fin design was completed early. In addition, over thirty fin dies were needed, but not all at the same time. Therefore, Carrier could tolerate staggered delivery of the fin dies. The dies that were needed first were ordered from local tooling suppliers and the others from the Chinese supplier. The left half of Figure 3-1 shows a diagram of the outdoor unit of a residential air conditioner and the right half clarifies what a fin is.

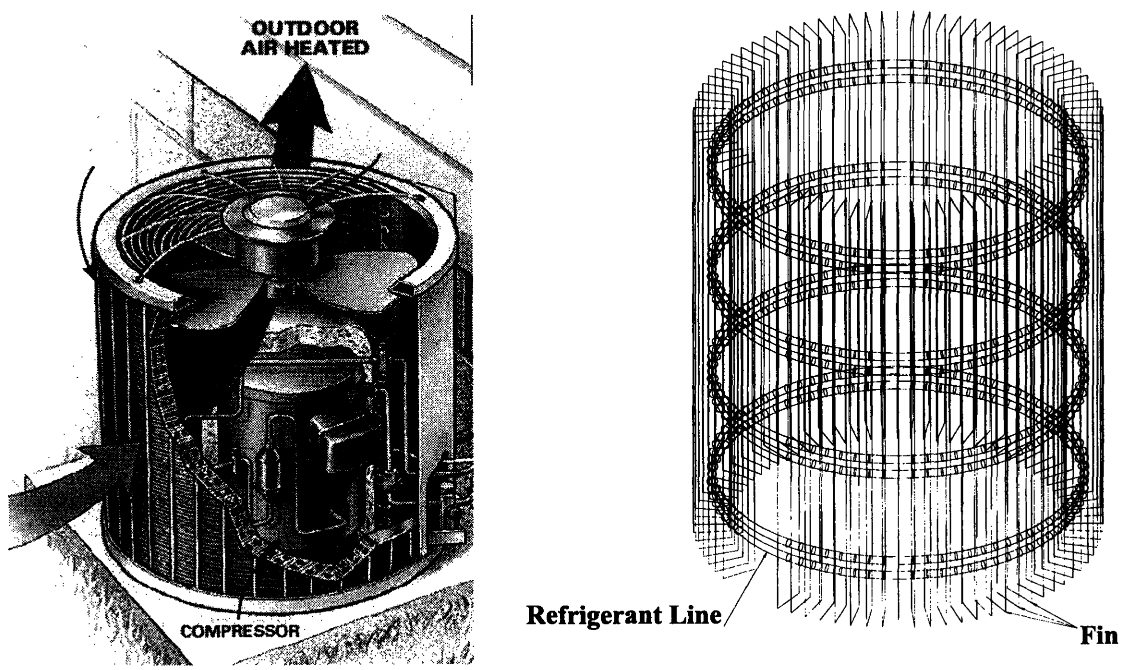


**Figure 3-1. Outdoor unit of a residential A/C (left). Wire frame model of fins and refrigerant lines (right).**

A fin is a part of the heat exchange unit: refrigerant lines are piped through the fins which serve as the heat exchange medium to cool the refrigerant. The fan sucks cold air from the outside through thin sheet metal fins; heat is transferred from the refrigerant to the fins and then to the air which is blown out the top of the air conditioner. As a result, heat is extracted from the refrigerant (it is cooled) and transferred to the air.

There are typically thousands of fins in the heat exchanger of an air conditioner which are very narrowly spaced – 25 fins per inch in some cases. Figure 3-2 shows the inserts that are apart of a sheet metal stamping (fin) die.

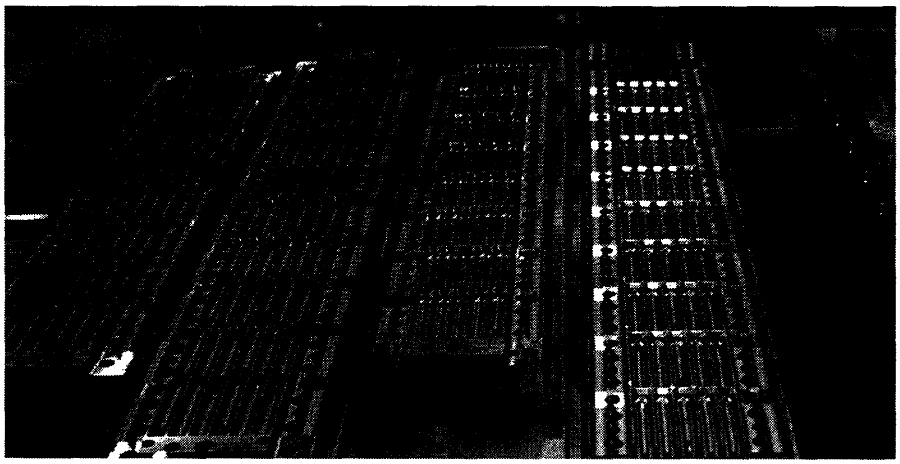

**Figure 3-2. Inserts for a sheet metal stamping (fin) die.**

There were in excess of thirty fin dies purchased for this program from two suppliers in the United States and one from China. Sourcing from a single supplier was not feasible because of the high volume of dies required. All of the fin dies were identical except for length; there were two different lengths (see Figure 3-2). Since all of the fin dies were basically identical, a direct comparison of the three suppliers can be made.

The first pass cost comparison that is commonly performed by purchasing is that of landed cost:

*Landed cost = cost + customs costs*[16] + *shipping costs*[17]

Landed cost is the cost incurred to get the product to the firm's shipping docks. It is only a first pass calculation to compare alternative sourcing options, and should only be a starting point. Durable tooling sourcing decisions should never be made using landed cost only; calculating the cost savings of one alternative over another using the landed cost usually overstates the savings because

[16] customs costs = duties + processing fee + brokerage fee
[17] shipping costs = freight + fuel surcharge + insurance

the calculation ignores hidden costs.[18] Real landed cost is a more accurate picture of reality because it includes less obvious costs that are actually incurred in getting the tooling into the factory and into machine so it is ready to use.

*Real landed cost = landed cost + hidden costs*[19]

Finally, this project deals with lifecycle cost which will be dealt with in more detail in Section 4.4.4.

*Lifecycle cost = real landed cost + maintenance costs*

## 3.2 Actual Fin Die Cost Comparison

The term cost could refer the purchase cost, landed cost or total cost. It is very important to be clear about cost. First, the landed cost is compared for all three sourcing options, and then the real landed cost to show the difference in cost savings. Total cost is addressed later in Section 4.4.4 in the lifecycle cost calculator. Figure 3-3 shows the landed cost comparison of the fin dies.


| | | | | | | |
|---|---|---|---|---|---|---|
| **Landed Cost:** | | | | | | |
| *Die Cost* | $ | 219,118 | $ | 309,750 | $ | 376,484 |
| *Total Customs Costs (duties, proc. fees, brokerage fee)* | $ | 13,080 | $ | - | $ | - |
| *Total Shipping Cost (freight, surcharge, insurance)* | $ | 16,995 | $ | 1,532 | $ | 1,002 |
| **Total Landed Cost** | $ | 249,193 | $ | 311,282 | $ | 377,486 |
| ***Landed cost advantage*** | | | | *24.9%* | | *51.5%* |

**Figure 3-3. Landed cost for sheet metal stamping (fin) die with air shipping.**

The Chinese supplier has a 25% landed cost advantage over US supplier 1 and a 51% landed cost advantage over US supplier 2. However, a landed cost comparison understates the actual costs of getting the fin die to the Carrier shipping dock; some hidden costs are not taken into consideration. In the case of the fin die the hidden costs are as follows:

- Shipping cost of try-out material – sheet metal roll
- Travel and boarding cost to supplier location for die qualification
- Commissioning cost – fitting die into press or machine and qualifying it
- Holding cost of capital

The following figure incorporates the hidden costs and shows a comparison of the real landed cost of the fin dies. For a complete description of the assumptions that go into calculating hidden costs see Section 4.4.4 Lifecycle Cost Calculator.

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[18] Womack, Jim. "Moving your operations to China? Do some lean math first." January 2003.

[19] hidden costs = shipping cost for try-out material + travel costs + commissioning cost + holding cost


| | | | | |
|---|---|---|---|---|
| **Landed Cost:** | | | | |
| *Die Cost* | | $ 219,118 | $ 309,750 | $ 376,484 |
| *Total Customs Costs (duties, proc. fees, brokerage fee)* | | $ 13,080 | $ - | $ - |
| *Total Shipping Cost (freight, surcharge, insurance)* | | $ 16,995 | $ 1,532 | $ 1,002 |
| **Total Landed Cost** | | $ 249,193 | $ 311,282 | $ 377,486 |
| ***Landed cost advantage*** | | | ***24.9%*** | ***51.5%*** |
| **Try-out Material** | **Hidden Costs** | $ 1,316 | $ 995 | $ 879 |
| **Total Travel Cost** | | $ 9,800 | $ 3,300 | $ 3,300 |
| **Commissioning Cost** | | $ 6,000 | $ 3,000 | $ 3,000 |
| **Cost of Capital** | | $ 2,922 | $ 4,130 | $ 5,020 |
| **Total Lifecycle Cost to Date** | | **$ 269,231** | **$ 322,707** | **$ 389,685** |
| ***Real landed cost advantage*** | | | ***19.9%*** | ***44.7%*** |

**Figure 3-4. Real landed cost for sheet metal stamping (fin) die with air shipping. Note: Travel and commissioning costs are estimates based on similar projects while the rest of the numbers are based on actual data.**

The real landed cost advantage of the Chinese supplier is 5% less than their landed cost advantage over US supplier 1 and 6.8% over US supplier 2 due to hidden costs. It is important to fully understand the hidden costs involved in a project. In the example above, hidden costs meaningfully reduced savings from low cost sourcing. If a die was not accepted the first time due to quality problems, the quality engineer could potentially have to make another trip to China to re-qualify the die once the supplier corrected the problems. The additional trip to China would have reduced the low cost sourcing cost advantage by another 4-5%.

A firm can find itself in a similar situation for many different reasons other than quality problems. For example, complex tooling may require a great deal of interaction with the supplier if the product or process is new. This scenario could require a manufacturing or engineering presence at the supplier location for weeks or even months during the manufacturing and testing phase of the sourcing process.

Situations like the two above (quality problems or higher than expected need for engineering/manufacturing support) can quickly destroy the value that low cost sourcing initiatives are expected to create and leave a firm worse off than before. It is therefore necessary to understand the risks associated with low cost sourcing. Section 1.6 reviewed some of these risks.

## 3.3 Target Case Fin Die Cost Comparison

The fin die comparison in the previous section was not ideal because the shipping method used to ship the fin die from China was air. The US suppliers used a low cost transportation option –

truck freight, while the Chinese supplier used a high cost transportation option – air freight. The target comparison, where all suppliers use the low cost transportation option is shown in Figure 3-5.

Ocean freight

| | | China | Supplier 1 | Supplier 2 |
|---|---|---|---|---|
| **Landed Cost:** | | | | |
| *Die Cost* | | $ 219,118 | $ 309,750 | $ 376,484 |
| *Total Customs Costs (duties, proc. fees, brokerage fee)* | | $ 13,080 | $ - | $ - |
| *Total Shipping Cost (freight, surcharge, insurance)* | | $ 6,000 | $ 1,532 | $ 1,002 |
| **Total Landed Cost** | | $ 238,198 | $ 311,282 | $ 377,486 |
| ***Landed cost advantage*** | | | *30.7%* | *58.5%* |
| **Try-out Material** | Hidden Costs | $ 1,316 | $ 995 | $ 879 |
| **Total Travel Cost** | Hidden Costs | $ 9,800 | $ 3,300 | $ 3,300 |
| **Commissioning Cost** | Hidden Costs | $ 6,000 | $ 3,000 | $ 3,000 |
| **Cost of Capital** | Hidden Costs | $ 2,922 | $ 4,130 | $ 5,020 |
| **Total Lifecycle Cost to Date** | | $ 258,236 | $ 322,707 | $ 389,685 |
| ***Real landed cost advantage*** | | | *25.0%* | *50.9%* |

**Figure 3-5. Estimated real landed cost for sheet metal stamping (fin) die with ocean shipping.**

The low cost transportation option for the fin die from China would be a combination of ocean freight (to a US port) and truck freight (from port to factory). Ocean freight is much more cost efficient than air freight (slightly more than one-third the cost of air freight). If ocean freight was used, there would have been a cost savings of 6-7% in the landed cost and 5-6% in the real landed cost versus those of air freight. However, there is a trade off: ocean freight takes approximately 4-6 weeks while air freight takes up to one week.

## 3.4 Fin Die Quality Comparison

The process capability of a tool/process is the main measure of quality used to certify a tool/process. Each fin die was qualified by running a batch of 60 parts and measuring numerous key characteristics (length, height, hole diameter, collar height, etc.) on each piece. See Appendix I – Machine and Tooling Qualification Procedures for an overview of Carrier's machine and tooling qualification procedure. A process capability value was calculated for each key characteristic measured. Process capability ($C_p$) determines whether the process (forming a fin) is capable by comparing the output of a process to the specification limits. The comparison is made by calculating the ratio of the spread between the process (desired) specifications to the spread between the process (actual) values and is measured as follows:

$$C_p = \min\left(\frac{USL - LSL}{6\sigma}\right)$$

The specification spread, usually determined by engineering, is the upper specification limit (USL) minus the lower specification limit (LSL) and is the acceptable variation of a key characteristic. The process spread is determined by the actual variation that the key characteristic exhibits and is represented by σ, the standard deviation of the process. There is approximately a 99.7% chance that the measured characteristic will fall between the 6σ spread (±3σ around the process mean). Thus, it is intuitive that a high $C_p$ value (lower actual variation than allowable variation) is desirable. A $C_p = 1$ indicates that the process spread and specified spread are equal. $C_p$ is the potential process capability of a process: it is an ideal scenario because it does not consider whether a process is centered on the target.

There is another process capability measure called $C_{pk}$ that takes into account whether a process is centered on the target and penalizes deviation from the mean. The formula for $C_{pk}$ is:

$$C_{pk} = \min\left(\frac{USL - \bar{x}}{3\hat{\sigma}}, \frac{\bar{x} - LSL}{3\hat{\sigma}}\right)$$

$C_{pk}$ splits the specification limit into two regions and incorporates the process mean. If the process mean is equal to the target, $C_{pk}$ is equal to $C_p$. If the process is not centered on the target, $C_{pk}$ will be lower than $C_p$. As a result, $C_{pk}$ is a measure of not only the process variation, but also how well the process is centered on the target. Carrier typically requires that the Cpk be greater than 1.33.

Figure 3-6 shows the process data for a die supplied by US supplier 1. The key characteristic (collar height) was measured on 60 fins. The target (ideal) collar height is 0.05 mm, but any value between the specification limits (0.0488 mm – 0.0512 mm) is acceptable.

**Collar Height - FM-162-2**
**Process Data**

| | | |
|---|---|---|
| LSL | 0.0488 | mm |
| Target | 0.0500 | mm |
| USL | 0.0512 | mm |
| Sample size | 60 | |
| Sample mean | 0.049744 | mm |
| Standard deviation | 0.000108 | mm |
| $C_{pk}$ | 2.91 | |
| $C_p$ | 3.70 | |

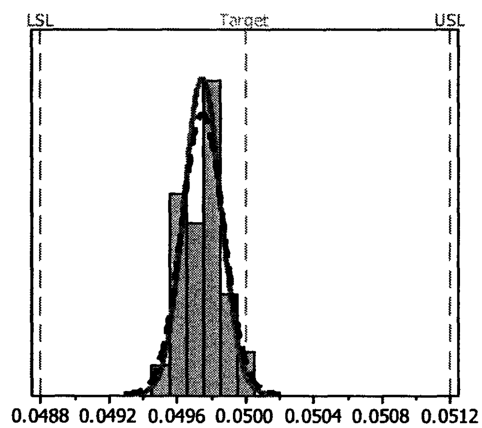


**Figure 3-6. Collar height process data for die FM-162-2 supplied by US supplier 1.**

The average collar height calculated from the 60 piece sample was 0.0497 mm and the standard deviation of the sample was 0.000108 mm. The bell curve in Figure 3-6 shows the range of probable values of collar height that a fin produced from die FM162-2 will have. The collar height will be between 0.0494 mm and 0.0501 mm (mean ±3σ) 99.7% of the time. The process capability ratios for the collar height of fins produced by die FM162-2 are $C_{pk} = 2.91$ and $C_p = 3.70$. Note that the $C_{pk}$ is less the $C_p$ of the process because the process is not centered on the target. However, the process is still considered capable because the $C_{pk}$ is greater than 1.33.

US supplier 2 measured eleven characteristics per fin: collar height on four different collars, fin length in four different locations, stack height in two different locations and one hole diameter. As mentioned earlier, each die produced 60 fins and the same eleven characteristics were measured on each of the fins. Consequently, each die has eleven process capability ($C_{pk}$) ratios associated with the fins it produces. Table 3-1 shows the process capability for six fin dies supplied by US supplier 1

**Table 3-1. $C_{pk}$ values for 11 fin characteristics produced by US supplier 1's fin dies.**

| Tool No. | Collar Height | Collar Height | Collar Height | Collar Height | Fin Length | Fin Length | Fin Length | Fin Length | Stack Height | Stack Height | Hole Diameter |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FM-162-1 | 4.60 | 5.64 | 5.30 | 6.41 | 3.70 | 4.29 | 3.14 | 2.78 | 1.03 | 1.03 | 0.74 |
| FM-162-2 | 2.91 | 4.29 | 3.07 | 4.39 | 5.32 | 2.30 | 2.54 | 2.01 | 2.32 | 2.48 | 2.97 |
| FM-162-3 | 5.31 | 9.41 | 5.76 | 12.07 | 3.88 | 8.79 | 7.76 | 7.90 | 3.17 | 3.22 | 4.16 |
| FM-162-4 | 6.31 | 8.11 | 6.72 | 5.98 | 8.03 | 7.23 | 5.62 | 6.52 | 2.07 | 2.35 | 2.94 |
| FM-159-4 | 4.31 | 3.05 | 2.04 | 2.33 | 3.69 | 4.34 | 5.05 | 5.00 | 2.84 | 2.25 | 3.44 |
| FM-159-5 | 8.76 | 6.38 | 2.88 | 6.78 | 5.42 | 7.37 | 8.01 | 5.71 | 2.38 | 3.88 | 5.32 |

There are sixty-six data points on the capability of US supplier 1's fin dies. The other two suppliers performed capability studies similar to the one described above. The aggregate quality of all three suppliers can now be compared. Figure 3-7 shows histograms of $C_{pk}$ values for all three suppliers.[20] US supplier 1 measured the same eleven characteristics on all six dies shipped to Carrier. US supplier 2 measured forty-three characteristics on fins produced by eleven dies in an unsystematic way. The Chinese supplier measured 20 characteristics on fins produced by one die. Note that not all dies have been shipped at this stage.

[20] The qualification procedure for the three suppliers differed. In the future, the qualification procedures in the Appendix should be followed. While this situation is not ideal, there is still information to be gained.

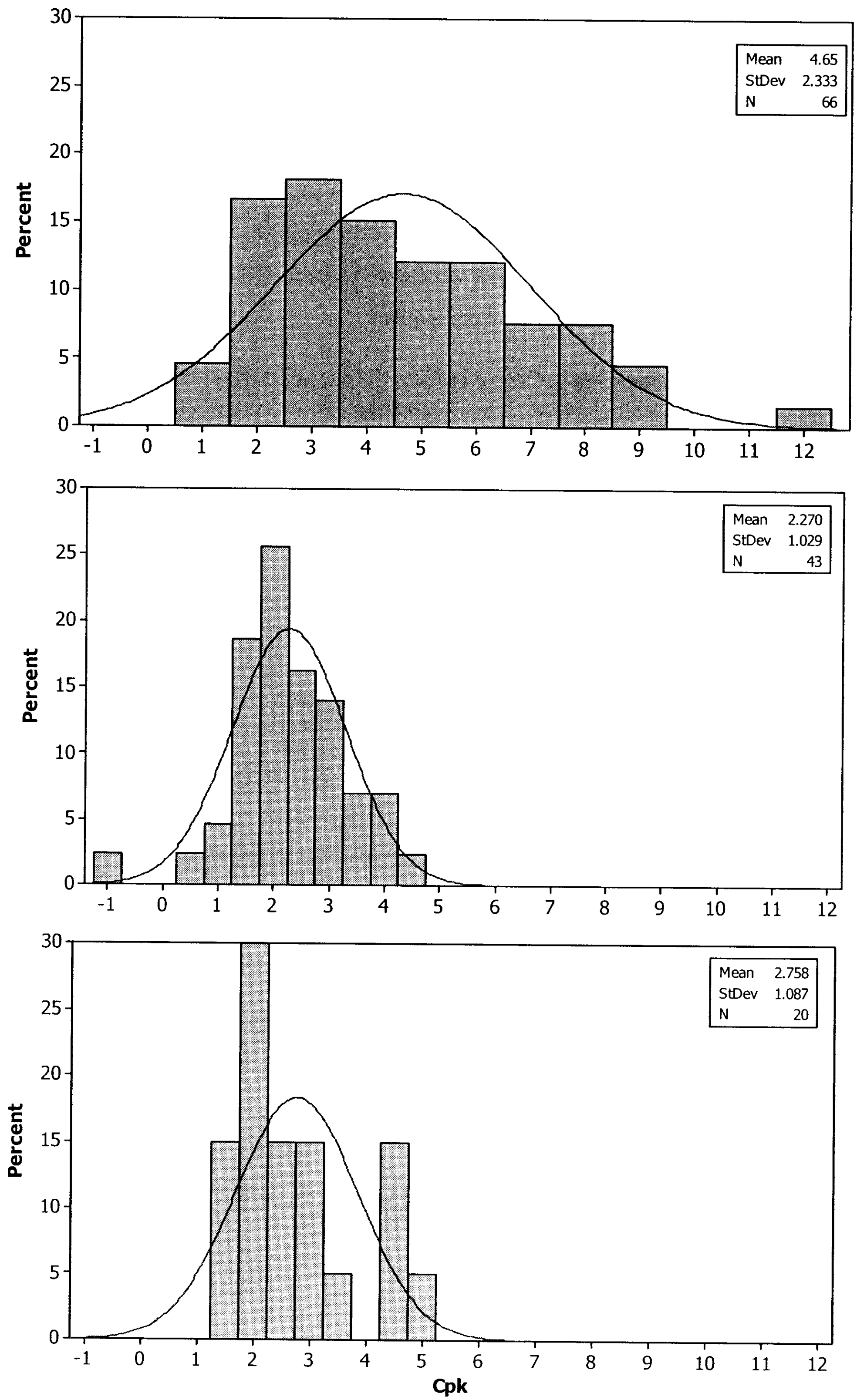


Figure 3-7. Distribution of $C_{pk}$ values: US supplier 1 (top), US supplier 2, Chinese supplier (bottom).

The implied probability distributions have been superimposed on the three histograms in Figure 3-7 and show the mean and standard deviation of each supplier's process capability ($C_{pk}$) values. Carrier requires having the $C_{pk}$ of all measured characteristics greater than 1.33 during full production, but usually will accept a die[21] if most characteristics measured have a $C_{pk}$ greater than 1.33. From the three histograms above, it is difficult to tell which supplier has the best quality. US supplier 1 has by far the best mean $C_{pk}$ but also has the highest variation. The Chinese supplier has a better average $C_{pk}$ but has slightly higher variation. Figure 3-8 shows all the process capability distributions overlaid to simplify visual comparison.

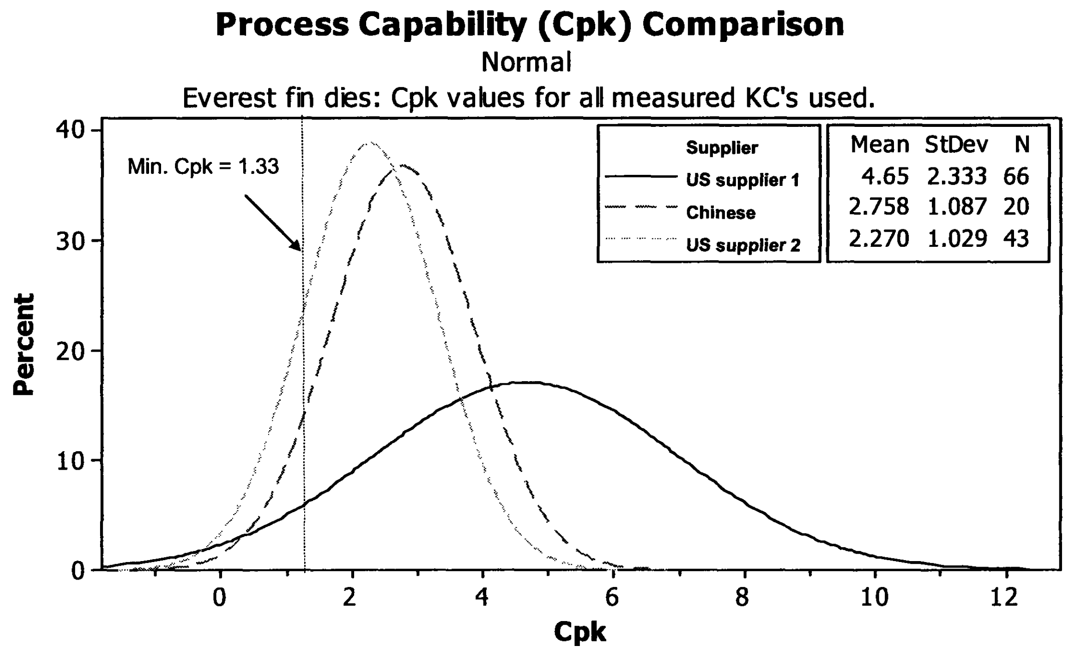


**Figure 3-8. Process capability comparison between all three suppliers.**

The distributions for the Chinese supplier and US supplier 2 have a similar shape; therefore it is clear that the Chinese supplier has a lower probability (area under curve to the left of the dashed line) of having a Cpk value less than 1.33 than that of US supplier 2. However, it is not immediately obvious how US supplier 1 compares with the other two suppliers because the shape of the distribution for US supplier 1 is so different. As a result it is impossible to make a comparison of the areas under the curve where $C_{pk}$ is below 1.33.

One way to make a comparison between all three suppliers is to find z-scores for each supplier and use a standard normal distribution to calculate the probability that the next $C_{pk}$ value

[21] The die and production process must be re-qualified at Carrier before production starts. During this qualification, all measured Cpk must be greater than 1.33 or the die/process is non-conforming.

calculated from measuring one more key characteristic is below 1.33. The z-score is calculated as follows:

$$z = \frac{X - \bar{x}}{\sigma}$$

$X$ is the raw score to be standardized ($X = 1.33$), $\sigma$ is the standard deviation of the sample, and $\bar{x}$ is the mean of the sample.

Table 3-2 shows the computed area under the curve for $C_{pk} < 1.33$ for all three suppliers. As was visually obvious above, the Chinese supplier has a lower probability of having a $C_{pk}$ value less than 1.33 than does US Supplier 2. US supplier 1 has the lowest probability of having a $C_{pk}$ value less than 1.33. As a result, US supplier 1 provided the best quality work followed by the Chinese supplier and then US supplier 2. In addition, the average $C_{pk}$ for US supplier 1 is substantially larger and this overall quality beyond the minimum requirement is of additional benefit.

**Table 3-2. Supplier quality comparison.**

| Supplier | Probabilty of $C_{pk}$< 1.33 |
|---|---|
|  1 | < 8% |
|  | < 10% |
|  2 | < 18% |

The result of the quality comparison seems counterintuitive in one respect. The Chinese supplier did not have $C_{pk}$ values that were below 1.33 while US supplier 1 had three, yet the die supplied by US supplier 1 has a lower probability of producing non-conforming parts. This unexpected result can be explained by the difference in the number of characteristics measured (in some sense a "sample size"). Since the Chinese supplier only qualified one die, there were only twenty $C_{pk}$ statistics with which to create a probability distribution versus sixty three for US supplier 1. As a result, there is much less certainty around the quality of the Chinese supplier and producing non conforming parts with their die is in the realm of possibility.

## 3.5 Chapter Summary

This chapter compared the cost and quality aspects of low cost versus domestic sourcing of fin dies. This case study showed that there is a potential for approximately 20 – 45% cost savings due to low cost sourcing. In addition, the quality of the die sourced from China was better than that of one US supplier and slightly less than that of another US supplier that Carrier currently deals with. This case study can help to dispel the pervasive myth that quality is poor in low cost regions.

# 4. Global Sourcing Strategy for Durable Tooling

This chapter presents the culmination of the internship that was the basis for this thesis. The global sourcing strategy for durable tooling has three goals: 1) low cost sourcing, 2) increasing coordination, and 3) leveraging global scale. Section 4.1 discusses the first goal, low cost sourcing, in terms of taking advantage of Carrier's already established low cost sources to minimize the total cost of durable tooling. Section 4.2 presents the second goal, the idea of increasing coordination between investment sites to reduce duplication of effort in durable tooling design and procurement. Section 4.3 discusses the third goal, leveraging Carrier's global scale and scope in the procurement of durable tooling. Section 4.4 presents the Durable Tooling Sourcing Strategy and the five major making tools that are used in the decision making process: 1) sourcing decision matrix, 2) durable tooling preferred supplier database, 3) country selection framework, 4) lifecycle cost calculator and 5) balanced tooling supplier scorecard. Section 4.5 introduces the Durable Tooling Passport process; this document is the standard work module that will be integrated into Carrier's product development process.

## 4.1 Low Cost Sourcing

Chapter 2 made a case that there is an opportunity to significantly reduce costs by engaging in low cost sourcing, given the size of Carrier's spend in high cost regions (Figure 2-9 and Figure 2-12), and the large gap in labor rates between high and low cost countries (Figure 2-11). Chapter 3 showed that this was the case by comparing the real landed cost of fin dies sourced from China and the US. US supplier 1 was 20% more expensive than the Chinese supplier and US supplier 2 was almost 45% more expensive. Cost savings can be as much as 25% to 50% if low cost ocean transportation is used.

Table 4-1 presents the low cost sourcing migration plan for Carrier from 2004 to 2007, with the actual and potential savings of the plan assuming that a 30% cost savings[22] can be achieved.

[22] Aberdeen Group. "Maximizing and Sustaining the Next Big Supply Savings Opportunity Low-Cost Country Sourcing Success Strategies," 2005. In addition, 30% cost savings is a reasonable estimate given that the durable tooling case study in Chapter 3 showed a potential for 25-50% cost savings.

**Table 4-1. Low cost sourcing migration plan.**

| | Year | High Cost Source Spend | Low Cost Source Spend | Tooling Spend ($ millions) | Total Savings ($ millions) |
|---|---|---|---|---|---|
| Actual | 2004 | 97% | 3% | 18 | 0.2 |
| | 2005 | 90% | 10% | 40 | 1.2 |
| Estimate | 2006e | 75% | 25% | 40 | 3.0 |
| | 2007e | 60% | 40% | 40 | 4.8 |

There is obviously a significant opportunity to reduce costs through low cost sourcing. However, most low cost sourcing initiatives appear to minimize the initial cost of durable tooling upon first inspection. Schedule delays, poor quality, poor project management, etc. can all translate to increased costs and leave a firm in a situation where it actually pays a higher price for low cost sourcing. The difficult part is to determine which tooling investments present a value creating proposition and which ones are value destroying. The sourcing decision matrix presented in Section 4.4.1, the country selection framework presented in Section 4.4.3 and the lifecycle cost calculator presented in Section 4.4.4 provide a methodology to assess which projects are right for low cost sourcing.

## 4.2 Increasing Coordination

Carrier has products that are marketed and manufactured in many regions in the world. In the past, the capital investments to establish manufacturing for these products was carried out at the factory level (i.e. each factory was responsible for procuring the capital equipment and executing the manufacturing strategy). One such product that was sold and manufactured in Latin America, Africa and Asia is the wall unit air conditioner which is shown in Figure 4-1.

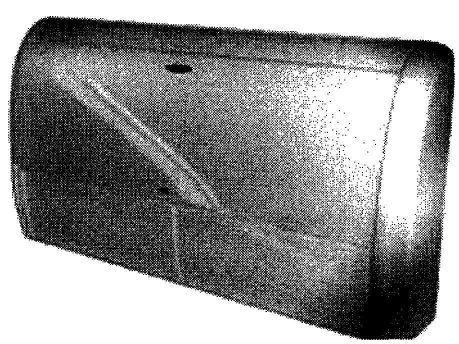

**Figure 4-1. Wall unit air conditioner manufactured in Brazil, Malaysia and Egypt.[23]**

[23] Illustration taken from a Carrier presentation – Durable Tooling Strategy: History and Future.

The result of this approach led to a duplication of efforts in procurement, design and manufacturing. The financial result of the missed opportunity is summarized in Table 4-2:

**Table 4-2. Tooling requirements for a wall unit A/C manufactured in the factories listed below.**[24]

| | Factory | | | | | |
|---|---|---|---|---|---|---|
| | Miraco - Egypt | | CISB - Malaysia | | SPG - Brazil | |
| | Cost (000's) | Supplier Location | Cost (000's) | Supplier Location | Cost (000's) | Supplier Location |
| Sheet Metal | $75 | Malaysia | $194 | Malaysia | $288 | Brazil |
| Platics | $192 | China | $257 | China | $706 | Brazil |
| Freight | $60 | | - | | - | |
| Total Cost (000's) | $327 | | $451 | | $994 | |
| | Base Case | | $124k opportunity | | $667k opportunity | |

Each factory paid for the design of the tool and sourced the build separately. As a result, multiple suppliers were paid to: 1) design the tooling as opposed to having one design shared between the factories, and 2) move up the manufacturing learning curve on a smaller number of tools rather than having one supplier use the learning benefits from the first set of tools to build the second and third set more efficiently.[25]

Had the sourcing decision been more central, the design and build of the tooling would have been sourced to Malaysia and China for all three factories. The resulting cost savings could have been significant[26] by eliminating duplicate tooling design efforts and economies of scale (learning effects) in manufacturing.

## 4.3 Leveraging Global Scale

In the previous example of the wall unit air conditioner that was manufactured in Egypt, Malaysia and Brazil, an opportunity to reduce costs through the economies of large scale buying was missed in addition to the learning economies of manufacturing. Another benefit of making the sourcing decision more central as in the above example is that Carrier can realize economies of scale in purchasing. The potential to reduce procurement costs through volume purchasing extends farther than the Platform level. Over 2004 and 2005, Carrier spent over $40 million in sheet metal dies from

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24

25 Manufacturing of tooling exhibits large economies of scale since each design is tailored for the process and part. Therefore, manufacturing missteps can be avoided on subsequent builds of the same tool.

26 If all three sites had the exact same manufacturing process and capacity, the potential savings could have been $124k + $667k = $791k by sourcing from the suppliers in China and Malaysia. While this is unlikely, there are still great benefits from coordination. Theses benefits are conservatively estimated to be $500,000.

more than 40 U.S. suppliers. Table 4-3 shows the number of U.S. sheet metal die suppliers by expenditure size. Note: the number of suppliers is understated because there is no data for $11 million of the $40.8 million spent on sheet metal dies.

**Table 4-3. U.S. sheet metal die suppliers categorized by expenditure size. (Note: there is no supplier data for $11 million of the following tooling spend.)**

| Tooling spend ($000's) | No. of U.S. sheet metal die suppliers |
|---|---|
| < 10 | 5 |
| < 100 | 14 |
| < 1000 | 15 |
| > 1000 | 6 |
| **Total = 40,800** | **40** |

Carrier spent less than $1,000,000 at 34 different suppliers. There is an opportunity to rationalize the supply base and reduce costs through volume purchasing. In addition to reducing costs, a smaller supply base reduces the complexity of Carrier's supply chain, making the job of the Supply Chain manager easier. Finally, it can allow the Supply Chain manager to focus on continuously improving a smaller supply base.

## 4.4 Durable Tooling Sourcing Strategy

For a given commodity, the best durable tooling sourcing strategy can be determined by answering the following questions: From which region should we source? From which supplier should we source? Built into these questions is the assumption that there is more than one supply chain to choose from. Why have more than one supply chain? The answer is that there is no "one size fits all" supply chain.[27] For example, consider the two scenarios. In the first scenario, a major section of a sheet metal stamping die that produces the base pan of an air conditioner breaks during production and there are only a few days of inventory (stamped base pans) available to feed the main air conditioner assembly line. After the inventory is depleted, the entire production process must be stopped. In the second scenario, a product launch is in two years and the product development team is looking for a sheet metal die supplier for a motor bracket that must be stamped. The design has been frozen and the product development team does not anticipate making any changes to this component.

It does make sense to consider the same subset of suppliers to do both of these tasks. Case 1 would require a local supplier, preferably one down the street, where the manufacturing team could

[27] J.L. Byrnes, "You Only Have One Supply Chain?," Harvard Business School Working Knowledge, Aug. 1, 2005.

drop in three or four times a day to answer any questions or provide assistance so that the die can be ready as soon as possible.

On the other hand, Case 2 does not require emergency action: the motor bracket is a relatively mature component and the product development team can shop around for a supplier that meets their cost and quality needs. There is enough time to deal with a supplier anywhere in the world to design and qualify the die and have it ocean shipped to the factory ahead of schedule.

These two cases are at opposite ends of the spectrum: there is no way that these two cases should be addressed by the same supply chain because their needs differ drastically. That is why Carrier should have three different supply chains – local, regional and global – to meet different sets of needs (Figure 4-2).

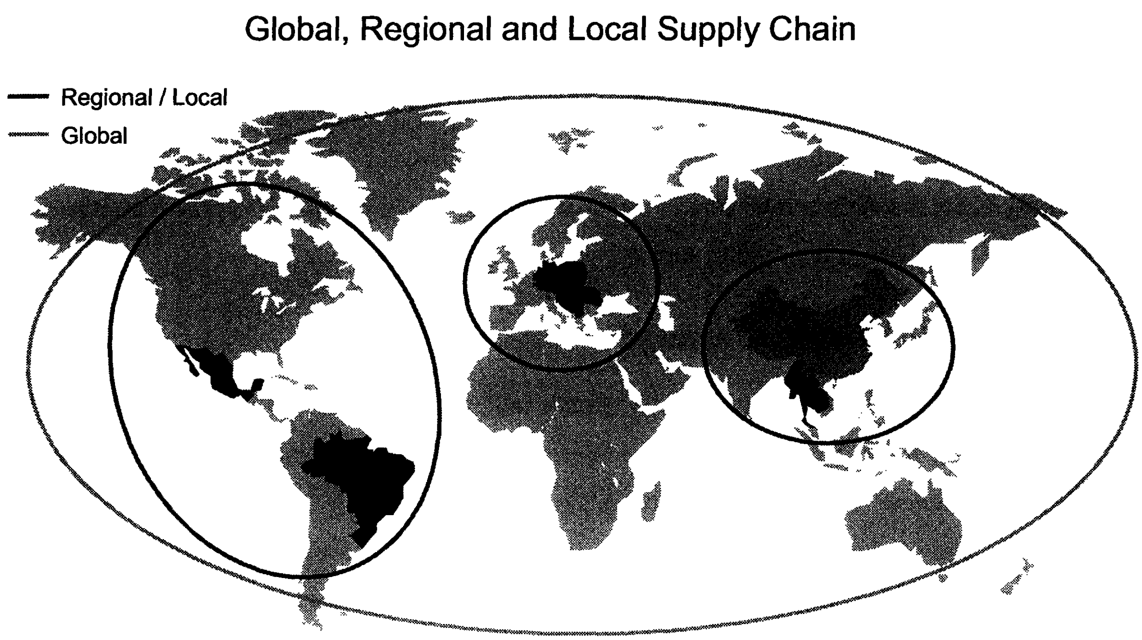


**Figure 4-2. Three different supply chains to meet differing needs.[28]**

Ideally, the solution would look something like this: Carrier should locally source durable tooling where rapid response (emergency repair, maintenance, etc.), unique availability (highly custom and complex) or a high level of integration is required. On the other end of the spectrum, Carrier should globally source tools that have a high value density (cost per dimensional weight) where cost savings outweigh logistics costs and/or longer lead times are permissible. However, the existence of capable suppliers in the low cost region is a prerequisite for any sourcing initiative.[29]

[28] Illustration taken from a Carrier presentation – Durable Tooling Strategy: History and Future.
[29] Since Carrier has factories that are globally dispersed, it also has a global tooling supply base that is capable of supplying most durable tooling needs.

Anything in between, Carrier should regionally source durable tooling to find the best combination of cost, quality and lead time.

The sourcing decision matrix helps to answer the question of which supply chain to utilize while the preferred supplier list, country selection framework and lifecycle cost calculator help answer the question of which suppliers to utilize. The following five tools (sourcing decision matrix, preferred tooling supplier database, country selection framework and balanced tooling supplier scorecard) present a framework for analyzing the sourcing decision for durable tooling in terms of risk and reward.

### 4.4.1 Sourcing decision matrix

The sourcing decision matrix helps us to decide whether to use the local/regional/global supply chains or a hybrid model for a specific investment in durable tooling. The decision is dependant on two factors: 1) lead time of tooling minus time to launch, and 2) complexity of the part/tool.

The complexity of the part/tool is an indicator of how much involvement or interaction is required from Carrier engineering and manufacturing personnel. A tool that is very complex may require a physical presence at the manufacturing facility of the supplier for parts of the build and qualification stages. A tool that is not complex may require little supplier interaction and only a part drawing to complete.

Lead time of tooling minus time to launch is an indicator of how soon the tooling is needed in the factory. For example, if 'tool 1' takes two years to design, build and qualify, and the scheduled product launch date is two years away, 'tool 1' now becomes in the schedules critical path and this process must be managed closely. On the other hand, if 'tool 2' takes six months to design, build and qualify and the product launch data is one year away, there is time to explore options. In the second case, even though the product launch date was one year away there was more time to act than in the first case which had a product launch that was two years away.

Each tooling investment can be mapped onto the lead time vs. complexity space of the sourcing decision matrix to get a big picture understanding of the project requirements. Figure 4-3 shows the sourcing decision matrix for the Everest program, where there were five sheet metal part families that required stamping dies.

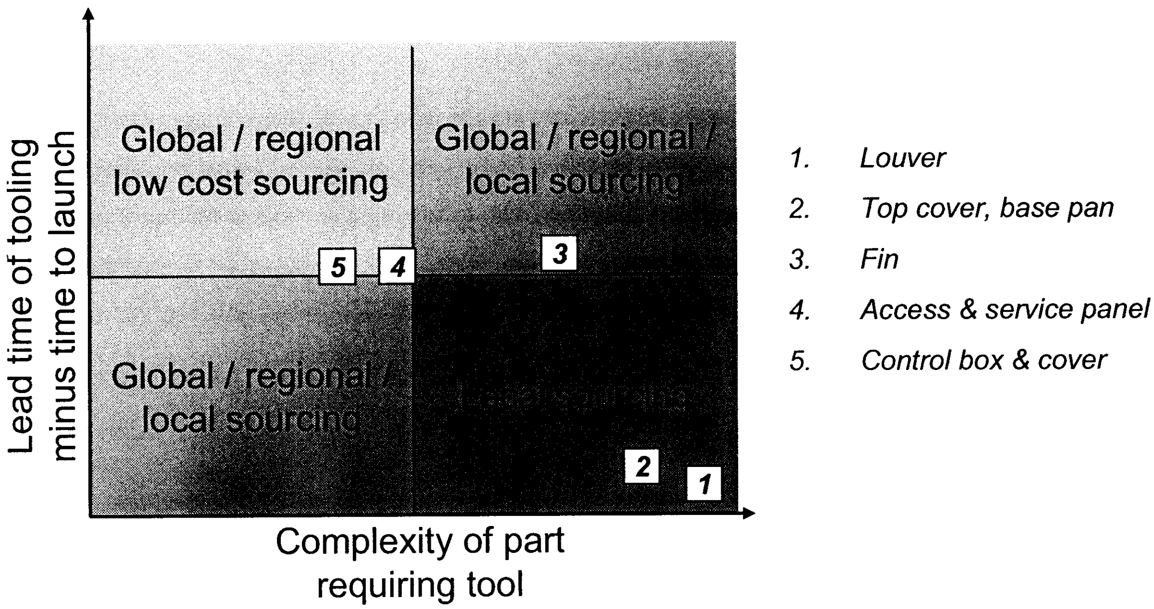


**Figure 4-3. Everest program durable tooling lead time vs. complexity matrix for five part families.**

There are two regions on the sourcing decision matrix where the decision is easy. The first is low complexity and lead time of tooling much smaller than the time to launch (solid green upper left corner) – tooling mapped to this quadrant is a strong candidate for global or regional low cost sourcing. The second is high complexity and lead time of tooling equal to time to launch (solid red lower right corner) – tooling mapped to this quadrant is a strong candidate for local sourcing.

The other two corners (lower left and upper right) require a more thorough analysis using the rest of the tools presented in this chapter as well as sound judgment and experience. Misjudgments made in these two quadrants can be very costly. Conversely, good judgments can lead to benefits that are difficult for competitors to reproduce.

The sourcing options for a tool that lies in either the lower left or upper right quadrant are as follows: 1) global sourcing, 2) regional sourcing, 3) local sourcing, and 4) hybrid sourcing strategy. There are also two options for hybrid sourcing. The first is to have local suppliers subcontract lower value work to Carrier's global/regional suppliers and manage the process. The second is to order tooling in phases if possible: for tooling that is required first, use local suppliers to aid in the development to resolve design and manufacturing problems. For the second phase, use global/regional suppliers on a proven, more mature design.

Determining the best sourcing solution from among the four options listed above requires detailed analysis. Some of the tools in the following sections will aid in this analysis:

***Preferred Tooling Supplier Database***. Identifies suppliers by region, capabilities and links to their performance history.

***Country Selection Framework***. Determines the relative risk of sourcing options from macroeconomic and infrastructure perspectives.

***Lifecycle Cost Calculator***: Determines the range of expected costs of durable tooling over its life for different sourcing alternative.

***Balanced Tooling Supplier Scorecard***: Used to understand the supplier's history on quality and delivery performance for past projects.

These tools can help mitigate some of the tangible risks associated with low cost sourcing but do little for intangible factors such as maintaining good relationships with suppliers and ensuring local supplier are not alienated. Maintaining three healthy supply chains will ensure the sustainability of cost savings as well as cost avoidance.

### 4.4.2 Preferred Tooling Supplier Database

The preferred tooling supplier database will give Carrier's product development team and manufacturing engineering teams information and access to tooling suppliers around the globe. The suppliers in the database have provided some type of durable tooling (sheet metal stamping die, plastic injection molding die or reusable container) to at least one Carrier manufacturing center in the past. In addition to having the contact information for the supplier and the Carrier factories that have dealt with the particular supplier, the database will also contain performance information and a link to the balanced supplier scorecard which is expanded upon in Section 4.4.5.

The preferred tooling supplier database will exist on Carrier's internal Strategic Global Sourcing website to provide easy access to the product development and manufacturing teams. The database is intended to be a living entity that is updated every time tooling is purchased whether it is for a new product launch, cost reduction activity, maintenance, etc. Figure 4-4 shows the tooling suppliers that were identified in the data collection process for this project.

**Plastic Dies**

| Country | Supplier | Carrier Contact |
|---|---|---|
| Korea | Buheung | CLK, Korea |
| | J Y Solutech | TCTC, Thailand |
| | JY Solutec | CLK, Korea |
| China | An Hui Tian Da | TongHui, China |
| | AnHui Anlan | CISB Malaysia |
| | Anlan | CLK, Korea |
| | Banda Star | CLK, Korea |
| | Ning Bo Yao Ma | TongHui, China |
| | Qiaoqi | QHC, China |
| | Wuxi TongHe | CISB Malaysia |
| Malaysia | Asia Mold | TCTC, Thailand |
| | Stylene | CISB Malaysia |
| Taiwan | Casting Technologies Inc. | Mexico Residential |
| | Honyi Precision Industry | Verdi, NV |
| Thailand | Eishin | TCTC, Thailand |
| | Power mold | TCTC, Thailand |
| | Srithai Metal | TCTC, Thailand |
| Czech Republic | Jelinek Trading | Linde, Czech Republic |
| | Mareka Services s.r.o. | Linde, Czech Republic |
| | Mifer | Linde, Czech Republic |
| Hungary | KNAUF Hungary | Jaszaroksallaz, Hungary |
| | METALPLASZT | Jaszaroksallaz, Hungary |
| | OVM-KARSAI RT | Jaszaroksallaz, Hungary |
| | SALZER FORMTECH | Jaszaroksallaz, Hungary |

**Sheet Metal Dies**

| Country | Supplier | Carrier Contact |
|---|---|---|
| Malaysia | MTL | CISB, Malaysia |
| Korea | CLK(Tool&Die Gr.) | CLK, Korea |
| Hungary | Bott | Linde, Czech Republic |
| | Operativ 2000 | Jaszaroksallaz, Hungary |
| China | Shenzhen Haiyang | QHC, China |
| | ***Wuxi Microresearch*** | Collierville, TN |
| Thailand | Unipart Metal | TCTC, Thailand |
| Czech Republic | Hydro Aluminium | Linde, Czech Republic |
| | Mechanika | Linde, Czech Republic |

**Link to supplier scorecard and project details**

**Reusable Containers**

| Country | Supplier | Carrier Contact |
|---|---|---|
| China | Shanghai Longhua | Yileng, China |
| Brazil | ISMA | Linde, Brazil |
| Hungary | Kaiser Kraft | Linde, Czech Republic |
| | Operativ 2000 | Linde, Czech Republic |

**Figure 4-4. Carrier preferred supplier list for plastic dies, sheet metal dies and reusable containers.**

The list is broken down by the type of tool (plastic injection molding die, sheet metal stamping die, reusable container), country of the supplier, supplier name and Carrier contact factory. Moreover, there will be a link to the balanced supplier scorecards of each supplier indicating their performance metrics on a project by project basis and overall.

### 4.4.3 Country Selection Framework

The country selection framework assesses the relative risk of sourcing in the low cost countries where Carrier has sourced durable tooling in the past. It evaluates countries on criteria that fall into three categories: 1) cost, 2) business risk and 3) workforce.[30] Table 4-4 shows the criteria that are used to evaluate a country.

**Table 4-4. Country selection framework metrics.**

| Category | Characteristic |
|---|---|
| Costs | Labor Rate (US$ / hr) |
| Business conditions and risk | Unemployment (%) |
| | Industrial Production Growth (%) |
| | Inflation (%) |
| | GDP Growth (%) |
| | Public Debt (% GDP) |
| Workforce | Literacy Rate (%) |

[30] A.T. Kearney. "Selecting a Country for Offshore Business Processing: Where to Locate," 2003

Each country is ranked from one to sixteen on each of the above criteria, with one being the best. The ranks of each country are added together to arrive at a final score (i.e. all criteria are equally weighted). The best score a country can receive is six (a rating of one in all six categories) and the worst score a country can receive is 96 (a rating of sixteen in all six categories). The countries are scored relative to each other; there is no baseline or ideal case. Countries are then ranked according to score so that the ranking is only a relative ranking of the countries involved in the comparison. Table 4-5 shows the results of the comparison.[31]

**Table 4-5. Country scores by characteristic.[32]**

| Region | Asia | | | | | | | | | Europe | | | | | Latin America | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Characteristic / Country | China | Singapore | India | Thailand | Taiwan | Philippines | Indonesia | South Korea | Malaysia | Turkey | Poland | Hungary | Czech Republic | Slovakia | Brazil | Mexico |
| Labor Rate (US$ / hr) | 4 | 15 | 2 | 5 | 14 | 3 | 1 | 16 | 8 | 6 | 10 | 13 | 11 | 12 | 9 | 7 |
| Unemployment (%) | 6 | 2 | 10 | 1 | 6 | 15 | 13 | 5 | 3 | 12 | 16 | 8 | 9 | 14 | 10 | 3 |
| Industrial Production Growth (%) | 1 | 2 | 4 | 4 | 13 | 16 | 15 | 7 | 10 | 9 | 3 | 6 | 8 | 12 | 11 | 14 |
| Inflation (%) | 2 | 1 | 11 | 12 | 5 | 15 | 16 | 6 | 8 | 14 | 4 | 10 | 3 | 7 | 13 | 9 |
| GDP Growth (%) | 1 | 3 | 2 | 10 | 13 | 9 | 5 | 11 | 6 | 7 | 14 | 11 | 8 | 4 | 16 | 15 |
| Literacy Rate (%) | 11 | 9 | 16 | 7 | 6 | 7 | 13 | 5 | 12 | 14 | 1 | 3 | 4 | 2 | 15 | 10 |
| Score (lowest is best) | 25 | 32 | 45 | 39 | 57 | 65 | 63 | 50 | 47 | 62 | 48 | 51 | 43 | 51 | 74 | 58 |
| Regional Rank | 1 | 2 | 4 | 3 | 7 | 9 | 8 | 6 | 5 | 5 | 2 | 3 | 1 | 3 | 2 | 1 |
| Overall Rank | 1 | 2 | 5 | 3 | 11 | 15 | 14 | 8 | 6 | 13 | 7 | 9 | 4 | 9 | 16 | 12 |

Labor rate determines the relative cost of the countries being compared. Naturally, lower cost receives a better ranking. The characteristics in the business conditions and risk category asses the risk due to the macroeconomic environment. More specifically, unemployment and GDP growth speak to the health of the economy. Low unemployment and high GDP growth indicate a healthier economy and rankings are assigned accordingly. Inflation is associated with higher prices (or lower purchasing power). Lower inflations receive a better ranking. Industrial production growth is an indicator of the health of the industrial sector. A higher industrial production growth receives a better ranking. Literacy is an indicator of the education level of the workforce. Intuitively, a higher literacy rate receives a better ranking.

The countries are ranked regionally and globally. The country selection framework is a useful tool to assist in deciding between sourcing alternatives. The sourcing alternatives should have already been passed through the sourcing decision matrix. The country selection framework should

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[31] Adapted from: Henkle, A L. "Global Supply Chain Design and Optimization Methodology." MIT, 2004.
[32] Ibid.

not be used in isolation; it is meant to be used with the portfolio of tools developed in this internship. Finally, the country selection framework can also be useful in choosing regions in which to develop suppliers. If a country or region is particularly attractive, a company may want to develop more suppliers there.

### 4.4.4 Lifecycle Cost Calculator

The lifecycle cost calculator is a tool that captures the hidden costs and uncertainty (via Monte Carlo simulation) in the durable tooling sourcing process. It is used to determine the total cost of ownership of durable tooling and can aid in financially evaluating a set of sourcing alternatives. As stated in Chapter 3:

$$\textit{Landed cost} = \textit{cost} + \textit{customs costs} + \textit{shipping costs}$$

$$\textit{Lifecycle cost} = \textit{RFQ cost} + \textit{landed cost} + \textit{hidden costs} + \textit{maintenance costs}$$ [33]

#### 4.4.4.1 Lifecycle Costs

***RFQ Cost*** – cost of Carrier personnel to generate a request for quote (RFQ), disseminate RFQ to suppliers, follow up to make sure that suppliers understand Carrier's requirements and ensure suppliers submit an accurate proposal/bid.

<u>Landed Cost</u>

***Cost*** – price quoted from supplier

<u>Customs Costs</u>

***Import Duties*** – depends on country of origin, destination country and commodity (sheet metal die, plastic injection molding die) and commodity subcategory.

***MPS Processing Fee*** – document processing fee

***Harbor Processing Fee*** – fee charged by port of entry

***Brokerage fee*** – fee charged by freight forwarder

<u>Shipping Cost</u>

***Freight*** – cost per kilogram, determined by mode of transportation and rated weight[34]

$$\textit{Rated Weight} = \max(\textit{Dimensional weight}, \textit{Actual weight})$$

$$\textit{Dimensional weight (lb)} = \frac{LxWxH\ (in^3)}{366\ (\frac{in^3}{lb})}$$

***Fuel Surcharge*** – depends on the price of fuel

[33] maintenance costs = maintenance + repair + replacement (for the life of the tool)
[34] Formula for dimensional weight provided by BAX Global.

***Insurance, Security*** – depends on freight forwarder/carrier (it is a percentage of the shipping value and does not change often).

**Hidden Costs**

***Shipping try-out material*** – cost of shipping material to supplier for testing and qualification. For a sheet metal stamping tool, this is the cost of shipping a reel of sheet metal to the supplier. For a plastic injection molding tool, this is the cost of shipping plastic pellets (molding material) to the supplier.

Travel Cost

***Design Review*** – cost of sending design engineer to supplier site for design review. (This may be done via teleconferencing in some instances instead of in person. If that is the case, the travel cost would be nil)

***Qualification Review*** – cost of sending a quality engineer to supplier site to qualify the tooling. (Carrier personnel should definitely qualify tooling at the supplier site to make sure that the tooling capability study is properly performed. It becomes much more costly when a tooling supplier must modify/rework tooling that is already at the Carrier factory as opposed to the supplier site.)

***Commissioning Cost*** – cost of setting tooling into the machine and qualifying the die at the Carrier factory.

***Inventory Holding Cost*** – Carrier typically pays 80% of the tooling cost when it is shipped. Tooling then sits idle (or is infrequently used) for a number of months until the product is launched.

$$Inventory\ Holding\ Cost = Cost \cdot 80\% \cdot \frac{y}{12} \cdot r$$

*where,*

*y = number of months tooling sits idle before program produces revenue*

*r = opportunity cost of capital (annual rate)*

**Maintenance Costs**

***Maintenance Costs*** – 8-15% cost of tooling on an annual basis with 10% being the most likely.[35]

[35] Estimate provided by Carrier Maintenance Department.

#### 4.4.4.2 Lifecycle Cost Calculator – Model Parameters

**Landed Cost Parameters**

The parameters that determine the landed cost of a tool are country of origin, destination country, mode of transportation, shipping dimensions, shipping weight, commodity and commodity subcategory.

***Import Duties*** = ***f*** (cost, country of origin, destination country, commodity, subcategory)

***Freight*** = ***f*** (cost, mode of transportation, rated weight)

**Monte Carlo Simulation Parameters**

The lifecycle cost calculator captures uncertainty in four cost components: RFQ cost, travel cost, commissioning cost and maintenance cost. Each of these random variables is a model parameter and is represented as triangular cost distributions for two reasons. The first, it is relatively easy (and intuitive) to characterize costs by a minimum, maximum and most likely value: most durable tooling stakeholders have a feel for these values. Second, data does not exist (in an economically retrievable format) to construct a real distribution for these costs.

Table 4-6 shows the minimum, maximum and most likely values for the cost distributions used in the lifecycle cost calculation in Figure 4-6.

**Table 4-6. Cost distributions parameters for Lifecycle cost calculator**

| | Min | Most likely | Max |
|---|---|---|---|
| **RFQ Cost** | $165 | $180 | $220 |
| **Travel Cost** | | | |
| Design Review | $7,500 | $8,000 | $9,000 |
| Qualification | $7,500 | $8,000 | $9,000 |
| **Commissioning Cost** | $2,500 | $3,000 | $4,000 |
| **Maintenance** | | | |
| % of Quote Cost | 8% | 10% | 15% |
| Maintenance Cost | $17,529 | $21,912 | $32,868 |

The cost distribution parameters are highly subjective and were determined by interviewing various Carrier manufacturing and supply chain personnel. As the durable tooling sourcing process matures and more data is collected, the triangular distributions may be modified to reflect the actual distribution of data. Figure 4-5 shows the triangular distribution that estimates the RFQ cost.

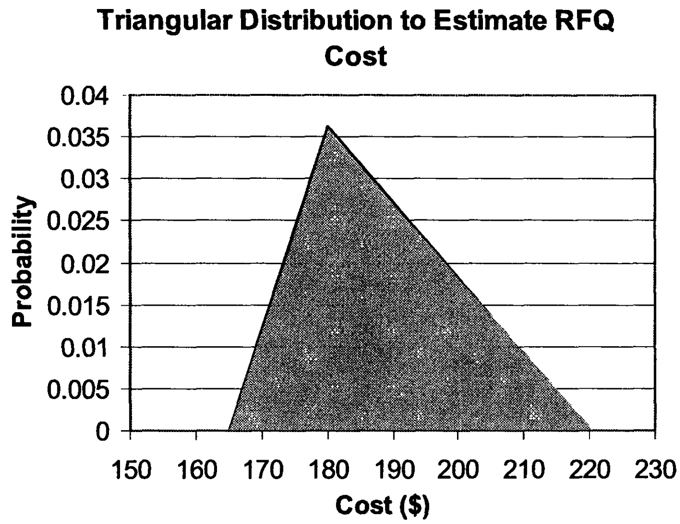


**Figure 4-5. Graphical representation of the triangular distribution used to estimate RFQ cost. (The shaded area is equal to one as is true of the area under the curve for any probability distribution.)**

#### 4.4.4.3 Lifecycle Cost Calculator

The Lifecycle cost calculator is a spreadsheet based tool that uses Crystal Ball to simulate a range of plausible lifecycle cost values. The model has two parameter entry areas: landed cost parameters and model simulation parameters (see Figure 4-6). The drop down menus and option buttons at the top of the model are used to specify landed cost. The cost distribution table specifies the parameters for the triangular distributions used in the simulation. To find the lifecycle cost, the user must enter numbers into the two cells that are highlighted in gray (cost, shipping try-out material), specify the landed cost by filling in the drop down menus, option buttons and text boxes, enter the model simulation parameters, and start the simulation.

| | | |
|---|---|---|
| **Country of Origin:** | China | |
| **Destination Country:** | USA | |
| **Approx. Shipping Dimensions:** | 160 x 120 x 90 | cm / in |
| **Approx. Shipping Weight:** | 5500 kg | |
| **Rated Weight:** | 5500 kg | |
| **Commodity:** | 8207.30 - Sheet metal dies | |
| **Sub Category:** | 30 - Suitable for cutting metal, and parts thereof | |
| **HS Code:** | 8207.30.30 | Tools for pressing, stamping/punching and parts thereof: Suitable for cutting metal, and parts thereof |

Air / Ocean - LCL / Ocean - FCL

Dimensional Weight = 131 kg

$$Dimensional\ weight\ (lb) = \frac{LxWxH\ (in^3)}{366\ (\frac{in^3}{lb})}$$

$$Rated\ Weight = \max(Dim.\ wt, Act.\ wt)$$

| | | | | |
|---|---|---|---|---|
| **RFQ Cost:** | | | | |
| **4 hrs x $45/hr** | | | | $ 180 |
| **Landed Cost:** | | | | |
| **Cost** | | | | $ 219,118 |
| **Customs Costs:** | | | | |
| Import Duties | 5.70% | $ | 12,490 | |
| MPS Proc. Fee | 0.21% | $ | 460 | |
| Harbor Proc. Fee | 0.025% | $ | 55 | |
| Brokerage Fee | | $ | 75 | |
| **Total Customs Costs** | | $ | **13,080** | |
| **Shipping Cost:** | $/kg | | | |
| Freight | 3.09 | $ | 16,995 | |
| Fuel Surcharge | 0.62 | $ | 3,410 | |
| Insurance, Security | 0.15 | $ | 825 | |
| **Total Shipping** | 3.86 | $ | **21,230** | |
| **Total Landed Cost** | | | | $ 253,428 |
| **Shipping Try-out Material** | | | | $ 1,316 |
| **Travel Cost:** | | | | |
| Design Review | | $ | 8,000 | |
| Qualification | | $ | 8,000 | |
| **Total Travel Cost** | | | | $ 16,000 |
| **Commissioning Cost** | | | | $ 3,000 |
| **Inventory Holding Cost** | | | | $ 2,922 |
| **Maintenance** | | | | $ 21,912 |
| **Total Lifecycle Cost to Date** | | | | $ 298,577 |

| Model Parameters - Cost Distributions | Min | Most likely | Max |
|---|---|---|---|
| **RFQ Cost** | $165 | $180 | $220 |
| **Travel Cost** | | | |
| Design Review | $7,500 | $8,000 | $9,000 |
| Qualification | $7,500 | $8,000 | $9,000 |
| **Commissioning Cost** | $2,500 | $3,000 | $4,000 |
| **Maintenance** | | | |
| % of Quote Cost | 8% | 10% | 15% |
| Maintenance Cost | $17,529 | $21,912 | $32,868 |

**Triangular Distribution to Estimate RFQ Cost**

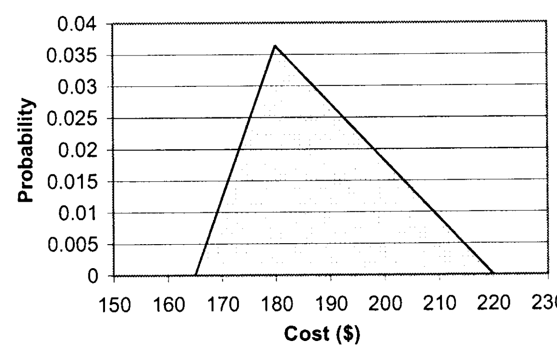


**Figure 4-6. Example of a lifecycle cost calculation.**

The lifecycle cost calculation in Figure 4-6 uses the average values of the random variables and the result is the average lifecycle cost. While the average cost, $298,577 is the most likely value, it says nothing about the range of plausible values for the lifecycle cost. The Monte Carlo simulation in Figure 4-7 shows the distribution of plausible values that the lifecycle cost can take on.

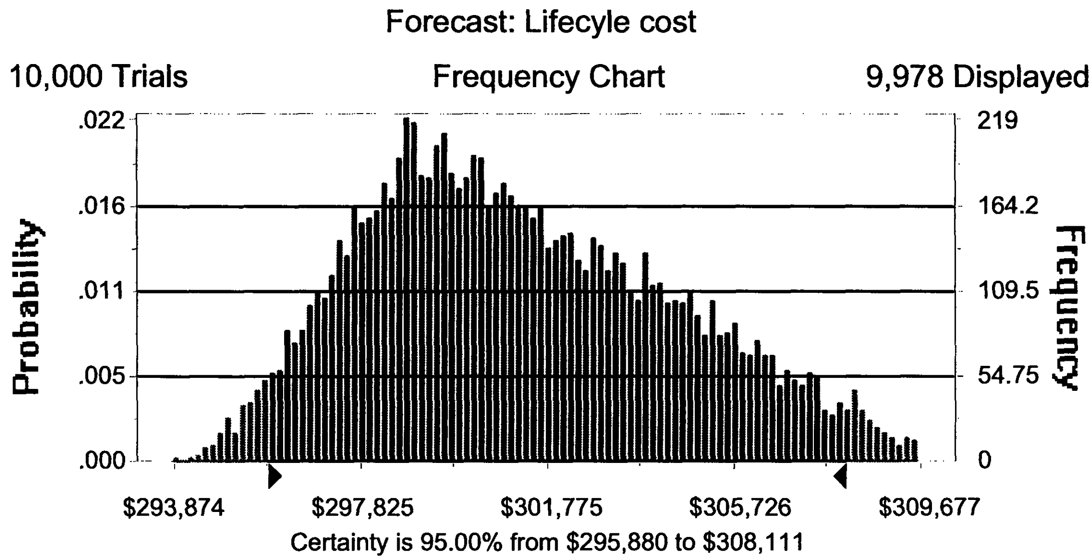


**Figure 4-7. Monte Carlo simulation of lifecycle cost.**

The simulation results confirm the obvious: the most likely lifecycle cost is between $298,000 and $299,000. In addition, the 95% confidence interval of lifecycle cost is from $295,880 to $308,111 (i.e. the lifecycle cost will be between with the interval 95% of the time).

The longer term benefit that will come from the lifecycle cost calculator is determining the source of variability. Comparing the lifecycle estimate to the actual expenditures of the project will provide information on the actual cost distributions and challenge conventional knowledge. The comparison will also identify opportunities for reducing the variability of costs.

### 4.4.5 Balanced Tooling Supplier Scorecard

The balanced tooling supplier scorecard[36] provides a comprehensive and easy to read performance summary of a tooling supplier: it measures tooling suppliers on four dimensions and weights them according to their relative importance. Delivery is counts for 40 points, tool acceptance counts for 10 points, quality counts for 40 points and, cost counts for 10 points.

[36] Kaplan and Norton. "The Balanced Scorecard: Measures That Drive Performance", Harvard Business Review, July 1, 2005.

All of the product development and manufacturing teams agreed that the four performance measures are the most important. The maximum score that a supplier can attain is 100 points. A detailed breakdown of the score is shown in Table 4-7

**Table 4-7. Balanced Tooling Supplier Scorecard point breakdown.**

| *Delivery - 40 points* | | *Tool Acceptance - 10 points* | | *Quality - 40 points* | | *Cost - 10 points* | |
|---|---|---|---|---|---|---|---|
| *Days Late* | *Points* | *Acceptance* | *Points* | *Cpk < 1.33* | *Points* | *Competitiveness* | *Points* |
| *< 10* | *40* | *1st Pass* | *10* | *0%* | *40* | *Market leader* | *10* |
| *< 30* | *20* | | | *5%* | *32* | | |
| *< 50* | *0* | *2nd Pass* | *5* | *10%* | *24* | *Competitive* | *5* |
| *< 70* | *-20* | | | *15%* | *16* | | |
| *>= 90* | *-40* | *> 2nd Pass* | *0* | *20%* | *8* | *Not competitive* | *0* |
| | | | | *>= 25%* | *0* | | |

### 4.4.5.1 Delivery – 40 points

The delivery score is based on the delivery date (i.e. the number of days late) and can take on a continuous score between -40 and +40 (i.e. twenty days late counts for 30 points). Delivery is an important performance measure and as such accounts for 40% of the overall score. It is the only performance measure than can contribute a negative number of points to the overall score.

In the past, some suppliers have delivered durable tooling two to three months late and many within Carrier felt that this was unacceptable and should be penalized. As a result, a supplier will be penalized 40 points for deliveries that are 90 days late. Moreover, many of within Carrier felt that if tooling was received within one week to ten days of the scheduled delivery date, this was acceptable. Consequently, the supplier will receive full points for deliveries that are less than ten days late. For all deliveries between the end points, the delivery score is linear between these end points (i.e. 0 points corresponds to 50 days late).

### 4.4.5.2 Tool Acceptance – 10 points

Tool acceptance occurs when a tool is qualified by either the manufacturing or reliability team at the supplier's location. If a tool is not qualified, the team must make another trip to the supplier site when the tool is ready to be qualified again.

Tool acceptance accounts for 10% of the overall supplier score. It is determined by which pass the tool is qualified on and is scored discretely. Ten points are awarded if the tool is qualified on the first attempt, five points if the tool is qualified on the second attempt, and no points are awarded otherwise.

While tool acceptance is correlated to delivery, it still merits its own category; both time and money are spent in qualifying a die and suppliers should be rewarded for getting the job done correctly the first time.

#### 4.4.5.3 Quality – 40 points

Quality is a very important performance measure and as such accounts for 40% of the overall supplier score and can take on continuous values between zero and forty. The score is determined by the process capabilities of the machine/tool.

Each machine/tool has a qualification procedure, as summarized in Appendix I – Machine and Tooling Qualification Procedures.[37] For example, the fin dies studied in this project were qualified by producing a number of fins and measuring the following characteristics on each fin produced: hole diameter, collar height, re-flare diameter, stack height and fin length. The process capability ($C_{pk}$) statistic was then calculated for each characteristic measured (see the balanced tooling supplier scorecard in Figure 4-8). The quality score was then calculated from the $C_{pk}$ values measured. More specifically, the score was calculated based on the percentage of $C_{pk}$ values that were below 1.33. The quality scoring is shown in Table 4-7. As stated above, the scoring is on a continuous basis (i.e., if the percentage of $C_{pk}$ values below 1.33 is 2.5%, the quality score will be 36 points).

#### 4.4.5.4 Cost – 10 points

Cost accounts for 10% of the overall supplier score and is also scored discretely. A supplier will receive the full ten points for being the market leader in cost competitiveness, five points for being competitive, and no points otherwise (not competitive).

#### 4.4.5.5 Supplier Score

There are three ratings that a tooling supplier can receive, good, fair or poor. A rating of good requires a score of 85 and above, a rating of fair requires a score of 50-85 and a rating of poor is given to a score of less than 50. Figure 4-8 shows a balanced tooling supplier scorecard for supplier PQRS for the Everest program.

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[37] Contributed by Bruce Poplawski, Carrier Corporation – Global Manufacturing and Quality Program Manager.

## PQRS Supplier

**Score: 87.7**

**Delivery - 40 points**

| Days Late | Points |
|---|---|
| < 10 | 40 |
| < 30 | 20 |
| < 50 | 0 |
| < 70 | -20 |
| >= 90 | -40 |

*Note: scored on a continuum (e.g. 20 days = 30 pts)*

**Tool Acceptance - 10 points**

| Acceptance | Points |
|---|---|
| 1st Pass | 10 |
| 2nd Pass | 5 |
| > 2nd Pass | 0 |

**Quality - 40 points**

| Cpk < 1.33 | Points |
|---|---|
| 0% | 40 |
| 5% | 32 |
| 10% | 24 |
| 15% | 16 |
| 20% | 8 |
| >= 25% | 0 |

*Note: scored on a continuum (e.g. 2.5% = 45 pts)*

**Cost - 10 points**

| Competitiveness | Points |
|---|---|
| Market leader | 10 |
| Competitive | 5 |
| Not competitive | 0 |

| Program | Commodity Type | Tool No. | Days Late | Score | 1st Pass | 2nd Pass | > 2nd Pass | Score | Cpk < 1.33 (frequency) | Cpk >= 1.33 (frequency) | Cpk < 1.33 (% of total) | Score | Cost Competitiveness | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Everest | Sheet Metal Die | FM-162-1 | 0 | 40.0 | 1 | | | 10 | 3 | 8 | 27.3% | 0 | Competitive | 5 |
| Everest | Sheet Metal Die | FM-162-2 | 0 | 40.0 | 1 | | | 10 | 0 | 11 | 0.0% | 40 | Competitive | 5 |
| Everest | Sheet Metal Die | FM-162-3 | 0 | 40.0 | 1 | | | 10 | 0 | 11 | 0.0% | 40 | Competitive | 5 |
| Everest | Sheet Metal Die | FM-162-4 | 0 | 40.0 | 1 | | | 10 | 0 | 11 | 0.0% | 40 | Competitive | 5 |
| Everest | Sheet Metal Die | FM-159-4 | 0 | 40.0 | 1 | | | 10 | 0 | 11 | 0.0% | 40 | Competitive | 5 |
| Everest | Sheet Metal Die | FM-159-5 | 0 | 40.0 | 1 | | | 10 | 0 | 11 | 0.0% | 40 | Competitive | 5 |
| TOTAL | | | | **40** | 6 | | | **10.0** | 3 | 63 | 4.5% | **32.7** | | **5.0** |

**Scorecard Summary**

| | Available Pts. | Earned Pts. |
|---|---|---|
| Delivery | 40 | 40.0 |
| Tool Acceptance | 10 | 10.0 |
| Quality | 40 | 32.7 |
| Cost | 10 | 5.0 |
| **Total** | **100** | **87.7** |

| Supplier Scorecard Rating | |
|---|---|
| Good | **85 - 100** |
| Fair | **50 - 84.9** |
| Poor | **< 50** |

**Figure 4-8. Balanced Tooling Supplier Scorecard for supplier PQRS.**

Each line item on the scorecard represents one tool. In the scorecard above, all six tools were sheet metal dies for the Everest program and each die was scored according to the four performance factors discussed above. The supplier received an overall score of 87.7 (good); as a result the top section of the scorecard is highlighted in green. In addition to an overall score, the supplier received a score on each of the four performance measures: perfect (*good*) scores on delivery and tool acceptance denoted by the green highlights and *fair* scores on quality and cost competitiveness denoted by the yellow highlights in the row labeled "TOTAL".

The balanced tooling supplier scorecard also helps to determine the relative risk of a sourcing alternative. Suppliers with high scores are less risky than suppliers with low scores. Moreover, the risk can be targeted specifically to delivery or quality. If the product development team is worried about delivery or quality, they will look at the supplier's delivery or quality score as well as their overall score to determine risk.

It is important to note that cost accounts for only 10% of the overall score while delivery and quality account for 80% of the overall score. This is due to the fact that quality and delivery issues can quickly turn into cost issues if production is interrupted or time to market is delayed.

As mentioned in Section 4.4.2, there is a link to the balanced tooling supplier scorecard in the preferred tooling supplier database. Since the scorecard will be one of the tools used to select suppliers, it must be kept up to date. Consequently, it is one of the milestones of the Launch phase of the Durable Tooling Passport process: the platform team supply chain member is responsible for ensuring that the supplier scorecard is up to date.

## 4.5 Durable Tooling Standard Work

The Durable Tooling Passport (standard work process shown in Figure 4-11) was the main deliverable of the internship that this thesis is based on. It was designed to be a module that fits into the existing framework of UTC's new product development process (Passport Process).

The Passport Process provides a disciplined approach to new product development by laying out a clear governance structure, a disciplined phase review process and a risk management plan. The Passport Process governs most activities that take place during lifecycle of a product.

The governance structure of the Passport process consists of an executive team (Platform Executive Board), a management team (Passport Review Board), cross functional teams (Platform Team and a Program Team) for each global Platform (product line). The Platform Executive Board (PEB) is made up of senior management and is responsible for prioritizing programs and articulating strategic issues to the Platform Team.

The Platform Team manages the entire lifecycle of the products in a business unit's portfolio. They are responsible for the execution of the Passport Process from concept to launch.

The Passport phase review process consists of six phases that every new product goes through: concept, specify, design, ready, launch and leverage. Each phase in the Passport Process has milestones and requirements that each of eight functional groups (management, marketing, engineering, reliability, supply chain, manufacturing, etc.) must meet. For example, engineering is required to have the *Final Design Release* completed during the Ready phase. Manufacturing must have the *Manufacturing Capital Estimate* completed and management must approve the *Capital Appropriation Request* during the design phase. These are just some examples of the milestones (in *italics* above) that each functional group must meet during the design phase of the Passport Process. All of the milestones in the Durable Tooling Passport (Figure 4-11) are a subset of the milestones in the Passport Process with additional instructions added to incorporate durable tooling.

For example, the *Sourcing Strategy* milestone addressed by the supply chain team in the design phase included sourcing of commodities and direct materials (motors, valves, compressors, etc.) only. The Durable Tooling Passport simply incorporates the durable tooling sourcing strategy into this milestone.

In addition, the *Final Supplier Selected* milestone addressed by the Supply Chain team in the Ready phase included selecting the suppliers of direct materials only. The Durable Tooling Passport extends this to durable tooling suppliers as well. All of the durable tooling stakeholders are a subset of the Platform Team members (Figure 4-9).

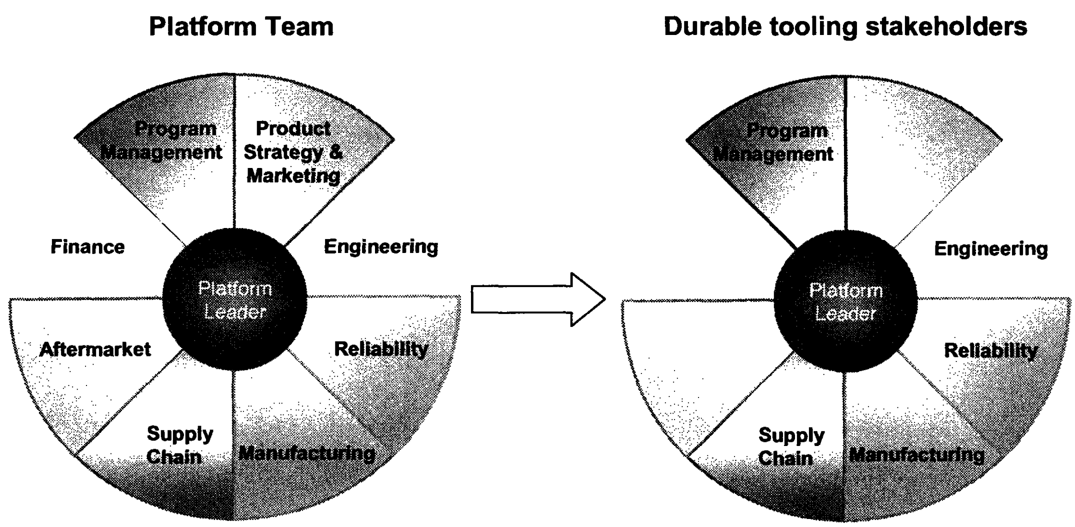


**Figure 4-9. Platform Team[38] members and durable tooling stakeholders.**

[38] Chopo Gómez Zoebisch, Editor. "Platform and Passport Guide." Carrier, November 2003.

The durable tooling stakeholders include Program Management, Engineering, Reliability, Manufacturing and Supply Chain. Only the five durable tooling stakeholders are on the vertical axis of the Durable Tooling Passport. The other three team members that are a part of the Platform Team (Finance, Aftermarket and Marketing and Product Strategy) do not have any milestones to meet for durable tooling; as a result they are not a part of the Durable Tooling Passport.

The Durable Tooling Passport is snapshot of the entire product development process as it relates to durable tooling. The phase review process goes into more detail on the milestones of each phase. Figure 4-10 is an example of the phase review process for phase 1 (Specify): each of the six phases has a review process similar to the one below.

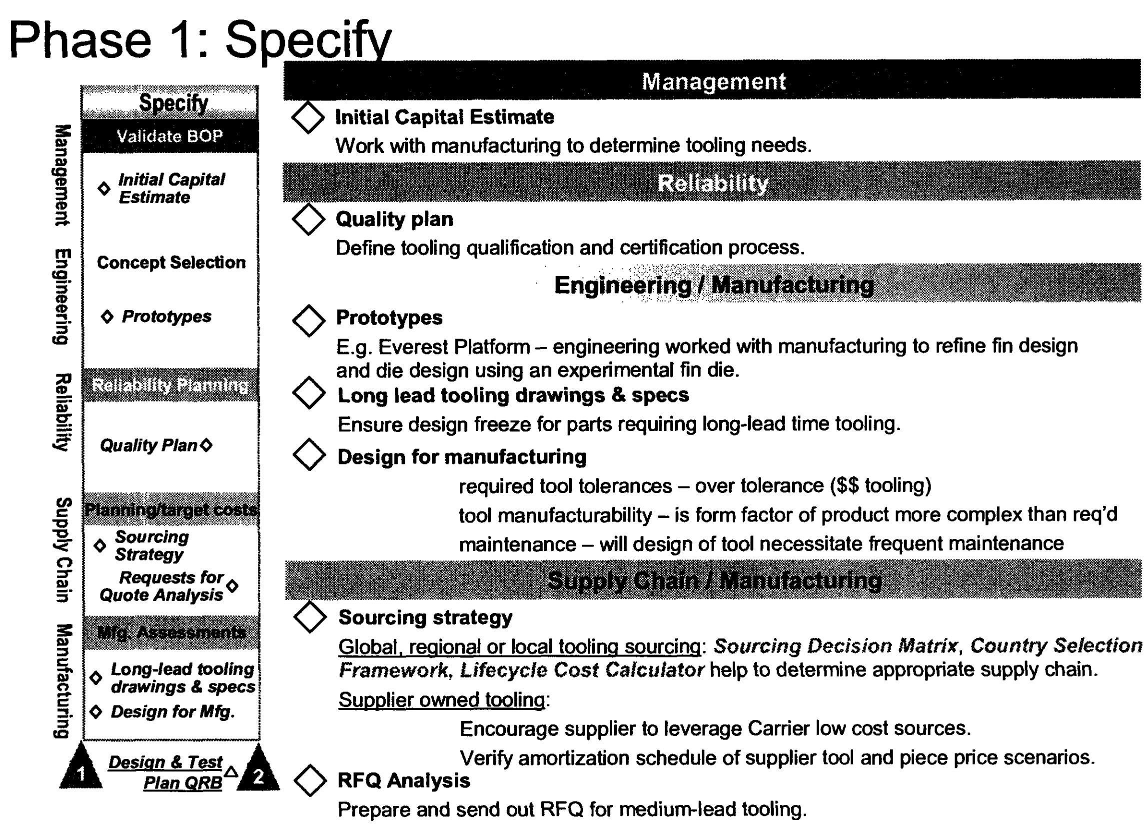


**Figure 4-10. Specify phase of the Durable Tooling Passport phase review process.**[39]

[39] Adapted from Gomez, 2003.

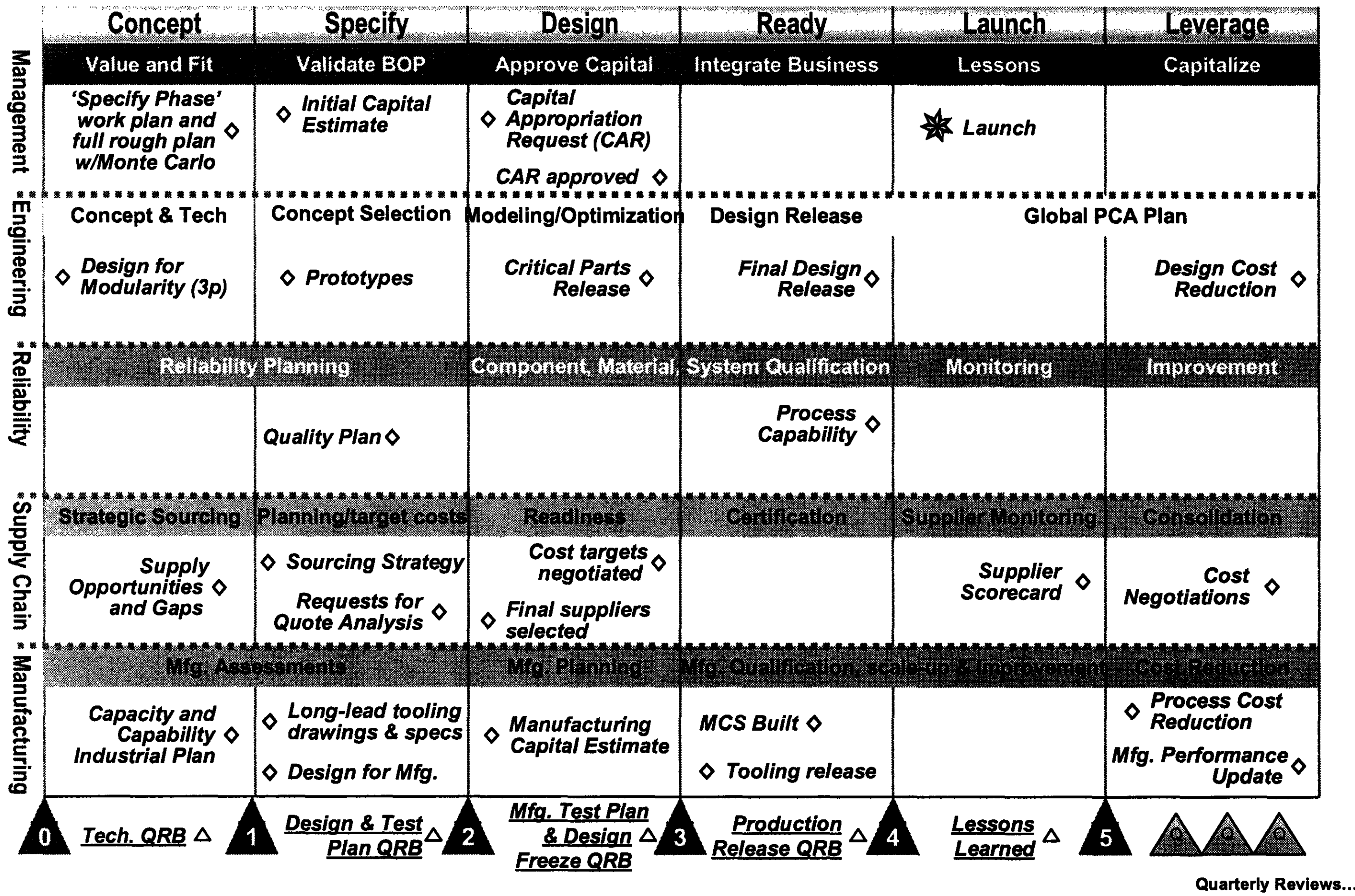


Figure 4-11. Durable Tooling Passport Process.[40]

[40] Adapted from Gomez, 2003.

The phase review process shown in Figure 4-10 is specific to durable tooling only. For example, the initial capital estimate milestone covers much more than just tooling, but for the purpose of the Durable Tooling Passport, only details related to tooling are included. The Passport Process contains all of the details of the initial capital estimate (in addition to the durable tooling) or has links to the information as will be the case for durable tooling.

Each phase in the Passport Process identifies milestones that must be completed in order to advance to the next phase ensuring that a project stays on schedule. The milestones in the Durable Tooling Passport ensure that tasks are completed on time so that any durable tooling issues do not delay the schedule. The phase review process should guide the work of the team members and the following checklist ensures that the required tasks are completed.

| Task | Responsibility | Phase 1: Specify |
|---|---|---|
| Initial capital estimate. | Management | ✓ |
| Define tooling quality and certification process. | Reliability | ✓ |
| Sourcing strategy identified. | Supply Chain / Manufacturing | ✓ |
| Estimated lifecycle cost calculated. | | ✓ |
| Sourcing decision matrix used for all major tools. | | ✓ |
| Country selection framework used to analyze country risk in low cost sourcing initiatives. | | ✓ |
| Prototyping of complex parts done. | Engineering / Manufacturing | ✓ |
| Long-lead tooling drawing freeze. | Engineering / Manufacturing | ✓ |
| Design for manufacturing considered. | Engineering / Manufacturing | ✓ |

**Figure 4-12. Specify phase team member checklist.**

The checklist for each phase must be completed before the project can advance to the next phase. However, the decision to advance from phases to phase is ultimately up to the Platform Leader just in case exceptions must be made. Nonetheless, the phase review process and the phase checklist give the team insight into the tooling process and how tooling can affect the overall schedule.

## 4.6 Chapter Summary

The goal of the internship at Carrier was to develop a global sourcing strategy for durable tooling. Chapter 4 identifies the three main issues and opportunities that the sourcing strategy was intended to address: 1) low cost sourcing, 2) increasing coordination, and 3) leveraging global scale. The chapter then presents the durable tooling sourcing strategy, a framework for analyzing the tooling sourcing decision in terms of risk and reward using the following five decision making tools.

The sourcing decision matrix is the first step in determining whether a tool should be sourced locally, regionally or globally. It determines which supply chain is appropriate for a given tool by comparing the complexity and lead time of a tool. If a tool is very complex and its lead time is equal to the time left until launch, the tool should be sourced locally. On the other hand, if a tool is not very complex and the tool can be delivered well before the scheduled launch date, it is an obvious candidate for global or regional low cost sourcing. If a tool is a potential candidate for global or regional low cost sourcing, the following decision making tools help to answer this.

The preferred tooling supplier database provides information on Carrier's current tooling suppliers and their performance information, and identifies the Carrier factories who have worked with the supplier before. The database identifies potential suppliers and sourcing alternatives.

The country selection framework compares the relative risk of sourcing alternatives and ranks each country by characteristic. The countries are then ranked globally and regionally by summing the individual characteristic rankings. The country selection framework and balanced tooling supplier scorecard assist in determining the risk adjusted cost savings of a sourcing alternative given by the lifecycle cost calculator.

The lifecycle cost calculator is a total cost of ownership model. It calculates the landed cost as well as a lifecycle cost of a sourcing alternative. This tool is used to compare the cost of sourcing alternatives. However, it should not be used in isolation; risk should also be considered.

The balanced tooling supplier scorecard measures supplier performance based on delivery, tool acceptance, quality and cost. Suppliers receive a score in each category and an overall score. This tool is used to measure supplier performance on an ongoing basis and can be also used to determine the delivery and quality risks of a sourcing alternative.

The durable tooling supplier standard work is the main deliverable of the internship and incorporates the durable tooling sourcing strategy (and the five decision making tools listed above) into the product development process. It is a module of the product development process and is used to guide the product development team's activities, as they relate to durable tooling, in the product development process.

# 5. Organizational Analysis At Carrier Corporation

This chapter analyzes the internship from three perspectives of organizational analysis to better understand the enablers and barriers to the implementation, follow through, sustainability and acceptance of the Durable Tooling Passport process. This chapter is adapted from a deliverable originally written for the course 15.317 – Leadership and Organizational Change.

## 5.1 Three Perspectives on Organizational Processes

Three perspectives on organizational processes will be used to analyze the potential enablers or barriers to successfully implementing and sustaining a global sourcing strategy for durable tooling (Durable Tooling Passport Process). The three perspectives, or lenses, that are used to analyze an organization are the strategic design lens, political lens and cultural lens.[41]

### 5.1.1 Strategic Design Lens

This organizational perspective examines the organization as a machine that has been designed to execute a strategy and accomplish goals. Tasks and activities are completed by functional or *strategic groups* that are *linked* together and whose efforts are *aligned* with the overall organizational strategy.[42] Strategic design is concerned with task definition, resources and the reward system.

Within Carrier Corporation, examples of functional or strategic groups include Aftermarket, Engineering, Finance, Manufacturing, Marketing, Quality and Reliability, Supply Chain, etc. The functional groups are linked together by Platform Teams which are responsible for product lifecycle management. Since the Durable Tooling Passport is a module or sub activity of the Passport Process, all of the linking and aligning mechanisms already exist. For example, Platform teams (via the Passport Process) already have processes in place that address sourcing of commodity products like motors, valves, compressors, electronics or controls; thus, the structure and networks are already in place for implementing the Durable Tooling Passport Process. As a result, Carrier is set up to be an enabler for developing, implementing and sustaining the Durable Tooling Passport Process, from a strategic design perspective, i.e. *grouping*, *linking* and *aligning*.

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[41] John S. Carroll, "Introduction to Organizational Analysis: The Three Lenses," MIT Sloan School of Management Working Paper, July 2002.
[42] Ibid.

### 5.1.2 Political Lens

The political lens contradicts the assumption of 'organizational goals' established by the strategic design lens. Instead, one looking through the political lens sees stakeholders, coalitions and alliances each pursuing their own interests.[43] If those interests are conflicting, a power struggle can ensue. The political lens is characterized by coalitions, alliances and power bases – action comes through power.

The political lens helps us to see where power is gained or lost as a result of a change initiative, and consequently, islands of support and resistance. One consequence of the Durable Tooling Passport is that the factories lose some power because the sourcing decision moves one step more centralized, to the Platform (product development) Teams and away from the factories' manufacturing team. In some cases, these manufacturing teams have long-established relationships with their durable tooling suppliers. There is a trickle effect down the value chain as well; the local tooling suppliers lose some power as they are not always the default choice under the new system.

There seems to be a difference in the underlying interests of the stakeholders: executive management would like to minimize cost, manufacturing wants to maximize quality and minimize lead time, while the Platform Teams (project management) would like to strike the right balance. On the surface, all of these interests do not seem to be aligned; however, a deeper look reveals otherwise. To frame the problem differently, executive management, manufacturing and project management would agree that quality problems and schedule delays are costly and that the real interest of all stakeholders is to minimize total cost (i.e. to find the right balance of cost, quality and lead time). Therefore, it is critical to show that all stakeholders have a common goal. This internship attempts to address this issue by providing a set of decision making tools (Sourcing decision matrix, Preferred Supplier Database, Country Selection Framework, Lifecycle Cost Calculator and Balanced Scorecard) that assist in determining the total cost of ownership by taking cost, quality, risk and timing into account.

### 5.1.3 Cultural Lens

Organizational culture can be thought of as the set of *attitudes*, *beliefs*, *values* and *norms* that represent the character of an organization and provide the context for action within the organization. As a result, the cultural lens allows us to see how work gets done via *attitudes*, *beliefs*, *values* and *norms* as opposed to documented processes (strategic design lens) or coalitions (political lens).

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[43] Ibid.

As stated earlier, this project deals with re-sourcing not outsourcing, as the design and manufacture of durable tooling is already outsourced. From this perspective the goal that this project hopes to accomplish (re-sourcing) will not be a total culture shock to most stakeholders as in an outsourcing strategy. However, the percentage of sourcing to low cost regions is expected to increase and this is where one expects there to be some challenges in implementation and sustainability. There is a general *belief* within Carrier factories that low cost sourcing means contracting work overseas to the country with the lowest wage rate and that the work is of poor quality. In addition, the factories *value* their relationships with domestic durable tooling suppliers because they are supporting the U.S. economy.

The cultural barriers mentioned above must be addressed in order for the global sourcing strategy for durable tooling to be effective. This can be done by better communicating what the strategy is trying to do. Firstly, it must be shown that low cost sourcing does not mean low wage sourcing. The goal is to minimize total cost as a function of cost, quality and lead time. In some situations shipping may be prohibitively expensive or the lead time too large to engage overseas tooling supplies. In other cases the complexity of the tool is too high which necessitates domestic or local sourcing because there will need to be much interaction with suppliers. The important idea is that low cost sourcing does not mean that all durable tooling will be sourced from China: there is no cookie cutter approach to sourcing and each case must be evaluated to determine the best solution for all stakeholders. In addition, it makes sense to ramp up the low cost sourcing initiative slowly and use projects that have a high chance of success. This will allow the organization to learn in a controlled manner and perhaps reshape some of the prevailing *beliefs* and *attitudes* about low cost sourcing.

## 5.2 Summary of Lens Analysis

Each lens is given a score indicating whether it is an enabler (+), neutral (0) or barrier (-) to successful implementation and sustainability of the Durable Tooling Passport process.

**Strategic design lens score (+)**

Looking through the strategic design lens reveals that Carrier has the structure (teams and processes) necessary to easily implement and sustain the Durable Tooling Passport process. The deliverables from this internship will fit into the Passport (product development) Process like a module.

**Political lens score (0)**

From the political perspective, there may be a tendency for groups to pursue their own interests. Management prefers low cost while manufacturing prefers high quality. However, the total cost approach to sourcing of durable tooling can show that the interests of these two groups are actually more compatible than they appear.

**Cultural lens score (-)**

From the cultural perspective, the attitudes and beliefs of manufacturing about low cost sourcing, which is one of the main components of the durable tooling sourcing strategy, can be strongly negative. Therefore, Carrier should slowly ramp up the low cost sourcing initiative and use projects that have a high chance of success to reinforce the benefits rather than overemphasize the risks of low cost sourcing. In addition, Carrier should clearly communicate that the low cost sourcing strategy requires that all of the supply chains (local, regional and global) remain healthy: the intent is not to source all tooling from global sources.

## 5.3 Chapter Summary

Chapter 5 used three perspectives or lenses to analyze the aspects of Carrier's organizational design that would be barriers or enablers to the successful implementation and follow through of the Durable Tooling Passport. When Carrier is viewed through the strategic design lens, the processes in place and linking mechanisms (Passport Process and Platform Team) are enablers.

From the perspective of the political lens, the coalitions and alliances in place will tend to pursue perceived differing interests. However, these perceived differing interests can be reconciled by using the total cost of ownership approach to align the interests of executive management, manufacturing and project management. Therefore, coalitions and alliances in place are neutral (neither enablers nor barriers) to the implementation and follow through of the Durable Tooling Passport.

From the perspective of the cultural lens, most manufacturing company's perspectives of low cost sourcing are negative. In order to minimize this effect Carrier needs to slowly ramp up their low cost sourcing initiative and choose projects with a high chance of success, especially early on. As a result, the attitudes and beliefs of low cost sourcing will be a barrier to the successful implementation and follow through of the Durable Tooling Passport.

# 6. Conclusions and Recommendations

Although the methodology presented in this report to develop a global sourcing strategy for durable tooling is specific to Carrier and specific to durable tooling, several general conclusions can be drawn that can be applied to other firms and to the sourcing of indirect materials in general.
As a prerequisite to any sourcing initiative, this study proposed doing a spend analysis to determine the potential value that a strategic sourcing initiative could have as well as understanding the current process. Once the current state was understood, a decision process was outlined which can be used to determine the correct sourcing option. The following tools are used in the decision making process.

***Sourcing Decision Matrix.*** First, the sourcing decision matrix can be used to determine which supply chains are most appropriate for the given time frame and complexity of the tool. There are two instances where using the sourcing decision matrix produce a direct answer: 1) if the part/tool is very complex and there is little time left in the schedule – use local/domestic sourcing, 2) if the part/tool is not complex and there is time in the schedule – use global/regional low cost sourcing. The other two cases require more analysis, and a number of potential options are given.

***Preferred Tooling Supplier Scorecard.*** Second, the preferred tooling supplier database identifies potential suppliers in the region where the sourcing will take place. The database includes contact information for the Carrier factories that have worked with the supplier as well as links to their performance information (balanced tooling supplier scorecard).

***Country Selection Framework.*** Third, the country selection framework determines the relative risk of each of the candidate suppliers. It assesses financial, macroeconomic and labor characteristics for the country of each candidate supplier. Note that the risk can be adjusted to reflect a supplier's past performance using the balanced tooling supplier scorecard. If a supplier has performed superbly for Carrier in the past then that supplier can be given a lower score for risk.

***Lifecycle Cost Calculator.*** Fourth, the lifecycle cost calculator estimates the lifecycle cost of a sourcing alternative. It calculates the landed cost, the hidden costs and maintenance costs to arrive at a lifecycle cost. By estimating the lifecycle cost of the sourcing alternatives, the suppliers can be ranked on their cost competitiveness. This ranking can also be used in concert with the risk ranking generated from the country selection framework to map the risk vs. savings of each supplier's value proposition. The supplier with the best risk reward characteristic should be selected.

***Balanced Tooling Supplier Scorecard.*** Fifth, the balanced tooling supplier scorecard is meant to keep a running tally of a supplier's performance based on delivery, tool acceptance, quality and cost. This information can also be shared with the supplier to help them improve in the future.

***Durable Tooling Passport.*** Finally, the Durable Tooling Passport incorporates the five decision making tools into a standard process for the sourcing of durable tooling. The Durable Tooling Passport is a module in the overall Passport (product development) Process. This Passport Process guides the activities of Platform (product development) teams throughout the product development process. The Durable Tooling Passport guides the activities of the Platform team with respect to durable tooling and is the main out of this research.

## 6.1 Recommendations

***Platform Teams continuously improve process.*** Use Platform (product development) Teams to continuously improve the Durable Tooling Passport Process since they will use it for every new product introduction. In this way, they will own the process and have an incentive to improve it.

***Supply Management serves as a link between factories.*** Improve communication between corporate headquarters and factories about suppliers (i.e. balanced tooling supplier scorecard, preferred supplier database). Corporate supply management should serve as a *link* between factories for information sharing and best practices. Better information sharing between factories will result in generally better data integrity and will hopefully change some of the *beliefs* about the quality of work of low cost sources.

***Plant manager reviews capital appropriations for low cost sourcing suitability.*** Require plant manager to sign off on process improvements (outside of product development process) that require durable tooling. This will give him/her an option of going to a low cost source with longer lead time (typically) if it is financially justified. This will better align the incentives of the factory with the incentives of management.

The Platform (program) leader will be instrumental in the implementation and follow through of the sourcing strategy. Ultimately it is up the Platform leader to ensure that the Platform team follows the process outlined in the Durable Tooling Passport Process and more broadly the entire passport process. The milestones and checklist required to advance from one stage in the Passport Process to the next stage are at the discretion of the Platform leader, therefore he/she can make or break the process.

# 7. APPENDIX I – MACHINE AND TOOLING QUALIFICATION PROCEDURES

**Overview Recommendations for Measurement System Analyses and Machine Capability Analyses for Coils Shop Equipment**

This is an overview of what should be done regarding measurement system analyses and machine capability studies for coil shops.

I strongly encourage having a Carrier representative, knowledgeable in Coil Manufacturing, MSA and Cpk techniques, actively involved in the planning, execution, analysis, and review of the collected data and study results. It is my experience that without oversight by a customer (Carrier) representative, the results of these studies can become suspect.

KPO's & KC's
Some KCs will continue to be checked during routine production. Others may only need to be checked to qualify the machine, and then occasionally after that. This should be reflected in the process control plan.

**MACHINE:** Fin Press
**KEY PROCESS OUTPUT (KPO):** The Fin
**KEY CHARACTERISTICS (KCs):**
Measured KC's: Hole diameter, Collar Height, Reflare Diameter, Vertical-Pitch (in direction of feed), Horizontal –Pitch (row to row), Fin Length (measure 12 hole length).
Inspected KC's: Split flares, Burrs.

**MACHINE:** Hairpin Bender
**KEY PROCESS OUTPUT (KPO):** The Hairpin
**KEY CHARACTERISTICS (KCs):**
Measured KC's: Clamped Leg Length for each process stream, Free Leg Length for each process stream and Bend Radius for each process stream.
Inspected KC's: Ovality, Roll-In, Burrs, End Cut Quality, and Wrinkles.

**MACHINE:** Expander
**KEY PROCESS OUTPUT (KPO):** The Expanded Coil
**KEY CHARACTERISTICS (KCs):**
Measured KC's: Stick Out Hairpin End, If Applicable, Intermediate Tube Sheet Location, Stick out Open Tube End, Bell Depth, Bell inside Diameter, Flare Diameter, Expanded Tube ID, Bowing (2 dimensions), FPI (Fins per Inch) and Distance over Tube Sheet (left, right, and center).
Inspected KC's: Split Tube Ends, Fin Damage, Fin Compaction.

**MACHINE:** Tube Sheet Press
**KEY PROCESS OUTPUT (KPO):** The Tube Sheet
**KEY CHARACTERISTICS (KCs):**
Measured KC's: Hole Diameter, vertical-pitch, horizontal-pitch and other key feature dimensions and locations.
Inspected KC's: Burrs and Cracks.

**ADDITIONAL PROCESS INSPECTIONS REQUIRED:**
- Coil Lacing
- Leak Test
- Brazing
- Cleaning

**Gauge R&R Studies**
General requirements for a good Measurement System Analysis.

1) Document target value and specification range for the key characteristic being measured. If different sizes of the part are produced, provide target and specification range for all sizes produced.

2) For *measured* KCs: Perform complete Gauge R&R study for the measurement system to be used during routine production for each measured KC for each piece of equipment. Each process step requiring a measurement system should have dedicated measurement tools for that process. Every measurement system that is used to judge quality acceptance needs to have a Gauge R&R study performed. For measurement based KCs this must include:

a) Assess the adequacy of the gauge's resolution.
b) Completely document the gauge type.
c) Review and document the gauge calibration schedule and results. (Gauge bias.)
d) Review and document the sampling and measurement procedures.
e) Review, document, and follow a written procedure for performing gauge R&R.
f) Perform a fully documented gauge R&R study: 15 pieces, 2 operators (3 would be better), 3 measurements per piece per operator; performed according to gauge R&R "best practices," including random presentation of parts to operator, independence of operators' measurements, ideally the parts should be presented to the operator "blindly", etc. Proper analysis of gauge R&R data by ANOVA method (preferred) or Control Chart method (acceptable).
g) If measurement system is used over a wide measurement span, then check linearity of the gauge over range of part sizes.
h) All raw data and analysis results must be submitted for review. Not just the summary report of the final results of the study.

3) For *inspected* (attribute) KCs: Perform complete attribute R&R study for the inspection system to be used during routine production for each inspected (attribute) KC for each piece of equipment. For attribute based KCs this must include:

a) Complete documentation of the go/no-go gauge (n/a for visual insp., only).
b) Review and document the go/no-go gauge calibration schedule and results (n/a for visual insp., only).
c) Review and document the sampling and inspection procedures.
d) Review, document, and follow a written procedure for performing attribute R&R.
e) Perform a fully documented attribute R&R study - 40 pieces (at least), 2-3 operators and 1 expert (if available), 2 inspections per piece per operator - performed according to attribute R&R "best practices" (see 2.f, above). Perform proper analysis of attribute R&R data using "agreement between assessors" method.
f) Attribute R&R studies require that some of the parts be clearly "good", some marginally "good", some marginally "bad" and some clearly "bad." Finding the necessary parts to make up the 40 pieces needed in (e) should be achievable from within the machine capability part runs for the fin press and hairpin bender. Getting enough parts for the sheet-to-sheet coil (go/no-go) inspection may have to wait until initial production runs.
g) All raw data and analysis results must be submitted for review. Not just the summary report of the final results of the study.

**Machine Capability Studies**

1) Proceed to machine capability study only if gauge R&R results are acceptable. If R&R results are unacceptable, measurement/inspection system must be improved before proceeding.

2) Perform machine capability, based on short-term variability.

a) Provide complete documentation of the machine and its setup for the capability run.

b) Provide complete documentation (batch numbers, analyses, etc.,) of the raw materials being used during the capability run.

c) Allow a suitable "warm-up" period for the machine prior to capturing the parts needed for the capability run.

d) Collect the parts necessary for the machine capability study.

I. Fin press:

- Part set A: 30 consecutively punched fins from each row of the die, and least 15 holes long. KC's measured at this point are Hole Diameter, Collar Height, Vertical-Pitch, and Horizontal-Pitch (for multi row coils), Re-flare Diameter, and Fin Length. For Hole Size, Re-flare and Collar Height, measure a number of holes per row equal to the progression of the die. (i.e. 4-progression die, 4 consecutive holes. For all 20 fins measure the Vertical-Pitch, Horizontal-Pitch and 12 holes measurements per row.
- Part set B: sets of 5 consecutively produced fins beginning every $40^{th}$ fin in a run of 800 fins produced for rows 2, n/3, 2n/3, and n-1. i.e. collect fins 1-5, 41-45, 81-85, etc. Fins must be identified in time order of production, row, and leading/trailing end. For each row measure the Hole Diameter and Collar Height. Be sure to measure the same hole per row. Plot in order of punch. Plot each row separate as well as all together. If there is a problem with the total not being in control, look at individual row data for inconsistencies.

II. Hairpin bender: Hairpins produced from 125 (minimum) cycles of the machine, with all streams in service. Hairpins must be identified in time order of production, by stream, and by leg (clamped or cut). For a 6-stream HPB this will mean 750 parts, total.

III. Expander: 30 consecutively produced coils, identified by time order of production.

IV. Turret press: 50 consecutively produced tube sheets, identified by time order of production.

3) Continuing machine capability for ***measured*** KCs:

a) Measure all KCs on parts collected above, using the measurement systems certified in gauges R&R.

b) Verify that each stream is in a state of statistical control, using subgroups of size 5.

c) If special causes are identified in (g), apply necessary corrective actions. Proceed to (i) only when process is in control.

d) Verify distribution of individual measurements for each steam.

e) If distribution in (i) is normal, compute short-term machine capability. If distribution in (i) is non-normal, apply transformations or other suitable advanced techniques for computing capability.

f) All raw data and analysis results must be submitted for review. Short-term machine capability should exhibit a lower 80% confidence bound on $C_{pm}$ of at least 1.67.

4) For attribute based KCs, machine capability studies include:

a) A suitably long run of zero-defect output to insure, with 90% confidence, that the true process defect rate is below some agreed-to target. Due to the number of samples that may be required, these studies may have to be a part of the initial limited production runs.

b) All raw data and analysis results must be submitted for review.

# 8. APPENDIX II – COUNTRY ECONOMIC STATISTICS

**Table 8-1. Country statistics.[44]**

| Region | Asia | | | | | | | | | Europe | | | | | Latin America | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Characteristic \ Country | China | Singapore | India | Thailand | Taiwan | Philippines | Indonesia | South Korea | Malaysia | Turkey | Poland | Hungary | Czech Republic | Slovakia | Brazil | Mexico |
| Labor Rate (US$ / hr) | 0.92 | 7.99 | 0.74 | 1.19 | 5.64 | 0.75 | 0.47 | 10.41 | 2.4 | 1.81 | 3.14 | 3.8 | 3.39 | 3.45 | 2.69 | 2.19 |
| Unemployment (%) | 4.2 | 3.3 | 9.9 | 1.4 | 4.2 | 12.2 | 10.9 | 3.7 | 3.6 | 10 | 18.3 | 7.1 | 9.1 | 11.4 | 9.9 | 3.6 |
| Industrial Production Growth (%) | 27.7 | 8.6 | 8.2 | 8.2 | 3 | 0.5 | 2.1 | 7.3 | 4.8 | 5.5 | 8.5 | 7.5 | 6 | 3.3 | 4.7 | 2.5 |
| Inflation (%) | 1.9 | 1 | 4.6 | 4.8 | 2.3 | 7.9 | 10.4 | 2.6 | 2.9 | 7.7 | 2.1 | 3.7 | 2 | 2.7 | 5.7 | 3.3 |
| GDP Growth (%) | 9.3 | 5.7 | 7.6 | 4.4 | 3.8 | 4.6 | 5.4 | 3.9 | 5.2 | 5.1 | 3.5 | 3.9 | 4.8 | 5.5 | 2.4 | 3 |
| Public Debt (% GDP) | 28.8 | 102 | 82 | 35.9 | 33.3 | 77.4 | 52.6 | 30.1 | 48.3 | 67.5 | 47.3 | 60.9 | 33.1 | 16.9 | 50.2 | 39.1 |
| Literacy Rate (%) | 90.9 | 92.5 | 59.5 | 92.6 | 96.1 | 92.6 | 87.9 | 97.9 | 88.7 | 86.5 | 99.8 | 99.4 | 99 | 99.6 | 86.4 | 92.2 |

[44] CIA, "The World Factbook 2005," 2005.

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