Impact of Shipping Ball-Grid-Array Notebook Processors in Tape and Reel on the PC Supply Chain

By

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Pamela Chuang

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Abstract

Today, approximately 90% of Intel notebook processors are packaged in PGA (Pin Grid Array) and 10% are packaged in BGA (Ball Grid Array). Intel has recently made a decision to transform the notebook industry by creating a new system size category called Ultrabook™. In order to create such a thin form factor, PGA (Pin Grid Array) CPUs must now be offered as BGA (Ball Grid Array) CPUs to reduce the height of one of the taller items of the system. With the increased number of Ultrabooks™ being offered, the overall volume of BGA CPUs shipped by Intel is expected to increase.

BGA CPUs can be shipped in one of two mediums: tape and reel or trays. By making tape and reel available, customers would be able to utilize the benefit of a more efficient pick and place process on their surface mount technology (SMT) lines compared to when using trays. However, from Intel's standpoint, BGA CPUs have a very high product mix, and shipping BGA CPUs in trays allows Intel to ship in smaller order quantities to customers. Intel currently ships its BGA CPUs in trays.

Because BGA processors used in Ultrabook™ and other systems will become the majority of processor volume, some customers have made a request to have BGA CPUs delivered in tape and reel in addition to trays. The objective of the thesis is to determine if packaging CPUs in tape and reel in conjunction with tray packaging will improve overall CPU supply chain performance.

Based on the analysis, we conclude that tape and reel should not be offered due to the minimal savings received by its ODM customers, and the expense that would be incurred by Intel based on current market conditions. Key drivers that influence this decision on the Intel side include SKU management issues, lack of shipping efficiency, and capital equipment purchase costs. From the customer point of view, it was identified that the request came from ODM Surface Mount Technology line managers and did not take into consideration procurement or inventory holding issues.

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Glossary

Term	Acronym	Definition
Advanced RISC Machines	ARM	Industry's leading provider of 32-bit embedded microprocessors
Ball Grid Array	BGA	A processor package soldered directly to the motherboard
Intel chipset		A set of chips that provides interfaces between all of the PC's subsystems[1]
End of Life	EOL	No longer manufactured or supported hardware[2]
Enterprise Resource Planning	ERP	An integrated software system that serves all departments within an organization[3]
Gross Margin	GM	A company's percentage of total sales revenue that the company retains incurring the costs of producing the goods and services sold by that company[4]
High Volume Manufacturing	HVM	Mass production; manufacturing standardized products in large quantities with assembly lines[5]
New Product Introduction	NPI	The stage at which a new product is introduced to the manufacturing line.
Original Design Manufacturer	ODM	A company that designs and manufactures a product, which is specified and eventually branded by another firm for sale.
Original Equipment Manufacturer	OEM	A company that rebrands equipment and sells it[6]
Operating Margin	OM	Ratio that measures a company's operating efficiency and pricing strategy[7]
Partialling		The process Intel employs to allow customers to purchase CPUs in partial tray quantities.
Pin Grid Array	PGA	A processor package attached to the motherboard via a socket
Quad Flat Pack	QFP	A type of semiconductor packaging

[1] (pcmag.com, 2012)
[2] (pcmag.com, 2012)
[3] (pcmag.com, 2012)
[4] (Investopedia, 2012)
[5] (Investopedia, 2011)
[6] (pcmag.com, 2012)
[7] (Investopedia, 2012)

Stock-keeping unit	SKU	A string of characters or numbers that uniquely identify a product[8]
Surface Mount Technology	SMT	A process used to mount electronic components on the surface of printed circuit boards or substrates[9]
Tape and Reel	T&R	A type of carrier packaging
Vendor Managed Inventory	VMI	Inventory managed by third party vendors; at Intel, these hubs are located near customer factories[10]

[8] (TechTerms.com, 2007)
[9] (Prasad, 1997)
[10] (Sailer, 2010)

1 Introduction

1.1 Thesis Motivation

The primary motivation of this thesis is to evaluate whether or not shipping BGA CPUs in tape and reel in addition to trays will improve performance in the overall notebook CPU supply chain. In order to achieve this goal, an analysis is done in order to determine whether or not BGA CPUs in tape and reel is a good value proposition for Intel from both an implementation and financial standpoint. This chapter presents an overview of the background, objective, methodology, and conclusions reached from this investigation.

1.2 Background and Objective

Notebook CPUs have always been packaged in one of two forms: Pin Grid Array (PGA) chips are ones that are connected to a motherboard via a socket, whereas Ball Grid Array (BGA) chips are soldered directly to the motherboard. A chipset is a group of integrated circuits designed to work together and help the CPU communicate with the rest of the motherboard. [11] Most of Intel's chipsets are packaged in BGA, whereas notebook BGA CPU volumes only make up 10% of total CPU volume. BGA packaged chips can be shipped in one of two mediums: tape and reel or trays.

Intel offers many different types of BGA CPUs to customers; hence, the company must manage a large number of Stock Keeping Units (SKUs). SKUs are unique identifiers used to identify unique processor types. However, Intel only offers a few types of different chipsets and therefore has a small number of chipset SKUs to manage. Historically, stand-alone BGA CPUs have always been delivered in trays, whereas chipsets have been delivered in tape and reel. There are many different reasons for this including:

- Different package sizes
- Lower SKU mix for chipsets making it easier to aggregate quantities conducive to tape and reel

[11] (Wikipedia, 2012)

- Lower cost for chipsets, reducing the inventory cost conducive to tape and reel

Intel has recently made a decision to transform the notebook industry by creating a new system size category called Ultrabook™, where one emphasis is on thinner, sleeker system designs. In order to implement this new roadmap change, Intel is required to implement BGA CPUs instead of using PGA CPUs. By implementing BGA CPUs, the socket will be removed thereby removing one of the taller items in the system. Hence, the trend to ultra thin and light notebooks may lead to more requests for shipments in tape and reel.

Intel has three major types of transport media it uses for different components it ships including plastic tubes, tape and reel, and trays. [12] Specifically for BGA CPUs, based on the experience with chipsets, Intel has the capability of shipping these components in both trays and tape and reel. There are advantages and disadvantages in receiving BGA CPUs in trays versus tape and reel; however, for high volume products customers prefer to receive BGA CPUs in tape and reel. By receiving BGA CPUs in tape and reel for high volume products, customers enjoy the benefit of a more efficient pick and place process compared to when using trays. Specifically, customers benefit from lower headcount and faster processing time.

From an Intel perspective, the disadvantages of tape and reel are impacts from a process, inventory, and transportation standpoint. Trays offer both customer order quantity flexibility and protection from shock and damage. In addition, substrates are delivered in the same trays that chips are shipped in, and therefore do not cost Intel anything.

Offering tape and reel as an additional shipping medium incurs a cost to Intel; however, the benefit to the customer can potentially generate positive outcomes for not just the customer but also for Intel. Because of the new increases in BGA CPU chip volume, customers have requested that CPUs be delivered in tape and reel in addition to trays. The goal of the project is to evaluate whether there is value that will be generated in the PC supply chain from Intel offering tape and reel in addition to trays in spite of Intel's initial investment costs.

[12] (Intel Corporation, 2004)

The hypothesis for this investigation is that though from Intel's perspective offering tape and reel is costly and difficult to manage, Intel could enjoy great benefits because of the overall gains that can be enjoyed by increased productivity of the entire PC supply chain. For large corporations, it is often difficult to examine such a large supply chain issue holistically and from a company centric point of view.

1.3 Research Methodology

The overall approach to whether or not to deliver BGA CPUs in tape and reel involves examining major issues that could arise before examining implementation details of how to ship BGA CPUs in tape and reel. This process allows the entire supply chain to be examined holistically rather than focusing on how individual parts of the supply chain will be impacted.

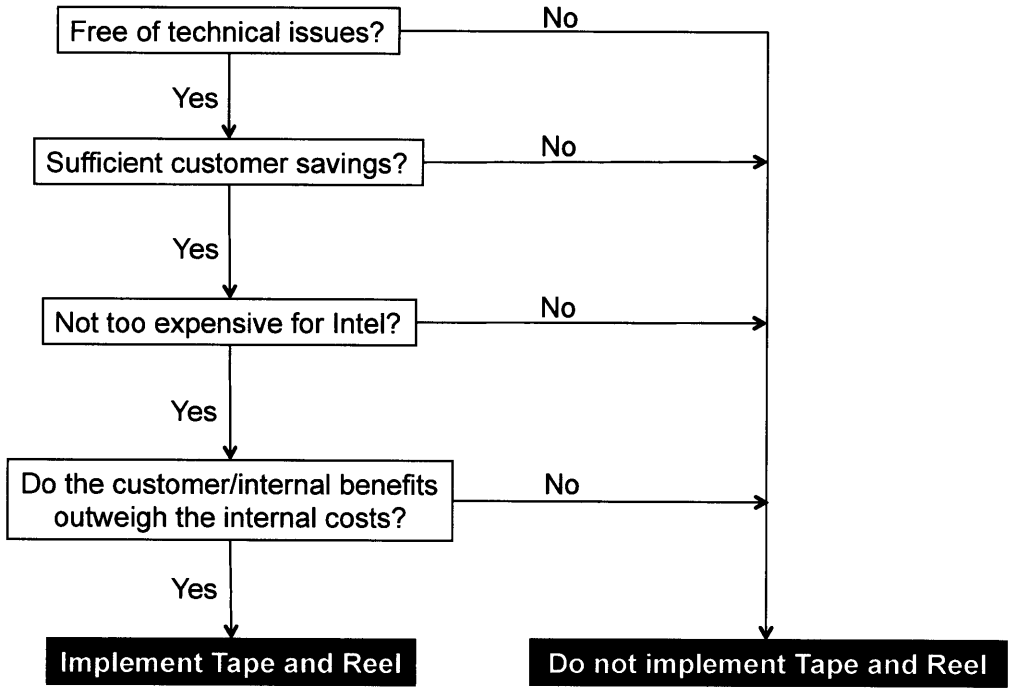

Figure 1: Tape and Reel Decision Tree

The first step is to do a big picture check of whether or not offering tape and reel as an additional shipping option in reality delivers value to the customer. This process involved working internally with the Customer Manufacturing enabling group to understand the initial customer request. In order to do this initial check, it must first be determined how many CPUs

will fit on a reel and then do a preliminary customer savings analysis. The process is demonstrated in Figure 1.

Once we determine that value could be delivered to the customer based on the customer's proposal, an internal analysis is conducted to analyze whether there are costs and technical risks that must be overcome in order to deliver processors in reels. The full internal analysis involves investigating the following areas of Intel's supply chain through interviews and collecting data sets from various stakeholders responsible for:

- Tape and reel design
- Tape and reel fragility
    - Shock testing
    - Vibration testing
- Warehouses
- Inventory Management
- Management of unique product types known as Stock Keeping Units or SKUs
- Assembly Test Manufacturing Platform Engineering
- Factory Capacity Planning
- Assembly Test Manufacturing Finishing Module

The interviews with each stakeholder involve collecting information about resources needed to support offering both trays and tape and reel as shipping mediums for BGA CPUs including:

- Additional headcount
- Capital equipment purchase
- Technical requirements
- System changes

Once the major hurdles are identified internally, a more detailed investigation is conducted to examine potential problem areas. The current issues that most greatly impact

the decision include issues of customer manufacturing efficiency gains and SKU proliferation handling.

After conducting the internal analysis, follow-up interviews were conducted with customers in order to understand both technical and financial requirements needed in order to receive BGA CPUs in tape and reel. These interviews gather customer data about:

- Inventory management
- Procurement
- Operator efficiency
- Pick and Place Processes

Once information is gathered from both the external and internal analysis, an overall cost-benefit analysis is conducted in order to determine whether or not Intel should offer customers the option of receiving BGA CPUs in tape and reel.

The tape and reel analysis requires help from multiple groups within Intel including groups working with customers, warehousing, demand forecasting, and manufacturing design. These groups have ownership to the following data sets necessary for the investigation: volume forecasts, material costs, inventory costs, ordering behavior, chip measurements, and machine limitations. The steps in the analysis summarized above are presented in more detail in chapters 6-9 of this thesis.

1.4 Company Background

Intel was founded in 1968 with headquarters in Santa Clara, California. As a world leader in silicon innovation, Intel develops technologies, products, and initiatives that change the ways people work and live.[13] The company is made up of 82,500 employees worldwide and its revenue in 2010 was $43.6 billion.[14] Intel has historically had a tick-tock strategy primarily focused in increasing processor performance. In recent years, priorities have shifted from

[13] (Intel Corporation)
[14] (Intel Corporation)

creating the fastest hardware to a focus on User Experience, Software (OS, Apps) with Processor/Hardware.[15]

Intel has adopted a strategy to develop PC products for higher mobility. An integral part of guaranteeing the success of this strategy is to align properly with PC OEMs.[16] Intel is going to great lengths in order to enable its OEM and ODM partners to build Ultrabooks™ including establishing a $300 million Ultrabook™ Fund and helping with both chassis materials and touch development with the goal of lowering costs.[17] In addition to investments and helping ODMs and OEMs with development, some speculate that Intel is also offering a $100 subsidy for every Ultrabook™ made to both ODMs and OEMs.[18] It is clear, based on Intel's investments and where it is investing R&D resources, that Intel is committed to making Ultrabook™ a mainstream product.

Historically, Intel has made several efforts to improve its customer service including by decreasing lead times through the creation of Vendor-Managed-Inventory (VMI) hubs.[19] Before the creation of VMI hubs, customer orders were fulfilled from Intel's component warehouse and took two weeks. Today, with VMI hubs in place, OEM customers replenish their customer orders in less than one week because these hubs are located close to customer factories. In addition to investing with its customers, the ODMs and OEMs, and decreasing customer lead times, Intel must also enable them to minimize costs for their manufacturing processes. As part of this effort, we investigate one method by which Intel can help its ODM partners manufacture products with BGA processors more efficiently in this thesis.

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[15] (Regis, 2011)
[16] (Gartner, 2011)
[17] (Crothers, 2011)
[18] (IT Reviews Staff, 2011)
[19] (Pai, 2009)

1.5 Thesis Structure

The thesis is organized in the following way. The first five chapters describe background about Intel and how it fits into the PC supply chain, the notebook manufacturing process, background about tape and reel and how it affects the SMT manufacturing process, Intel as an organization, and key differences between tape and reel and trays. Chapter 5 describes the methodology employed on how tape and reel is assessed from a technical and financial standpoint from both the customer and Intel's point of view. Chapters 6 through 9 identify key findings and describe technical and cost implications for both ODM customers and Intel. The final chapters provide recommendations, address key drivers that affect the tape and reel decision, and consider the possibility that external factors could affect the tape and reel decision. These chapters explore the likelihood of external drivers changing, which include OEM procurement policies, offering fan folded carrier tape as a new shipping medium, and technological advancements that could result in shipping BGA CPUs in tape and reel as a necessity or as a potential benefit to Intel.

2 Notebook PC Supply Chain

2.1 Overview

The present chapter describes where the PC ecosystem is today and how Intel fits into the PC supply chain. Many of today's current PCs are a combination of an Intel-based computer and a Windows-based operating system, often referred to as "Wintel". The demand for these systems is not growing as fast as it used to. [20] In today's market, demand for new devices such as tablets and mobile phones is growing at a much higher rate.

In addition to slowing demand growth, innovation in PC notebooks has stalled in recent years. As Taiwanese notebook production has moved to China, the PC supply chain is providing little contribution to upgrading China's capabilities in the notebook market. [21] Intel's current roadmap strategy, known as "tick-tock" and shown in Figure 2 in which a processor shrink alternates with an architecture change year after year, is not encouraging enough innovation throughout the PC supply chain. Intel's focus on processor performance and size as a strategy is no longer sufficient to grow demand for PCs.

[20] (Burt, 2011)
[21] (Yang, 2006)

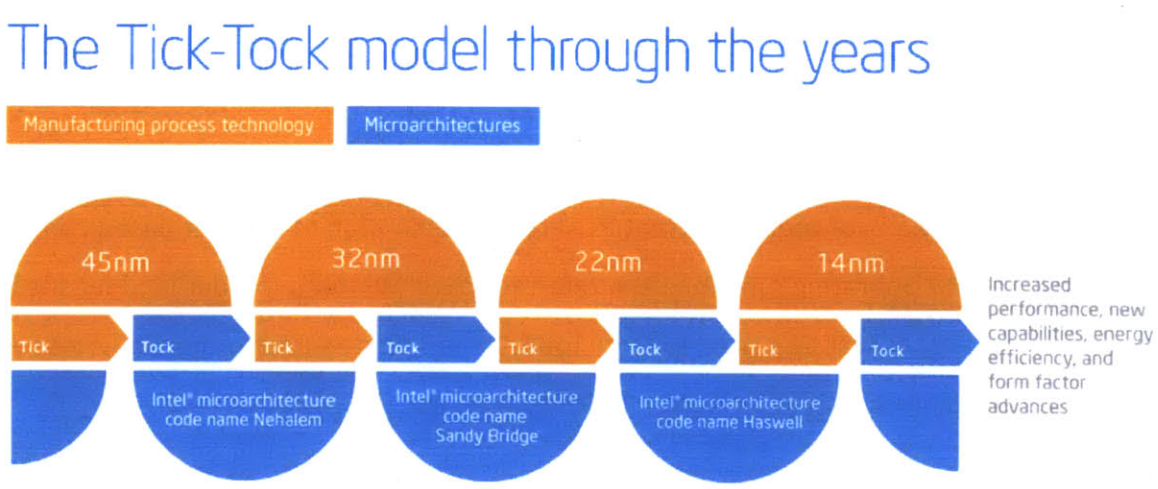


Figure 2: Intel Roadmap[22]

As a result, Intel must take a new approach in order to make an effort to reinvigorate the PC ecosystem. Paul Otellini, the CEO of Intel, said to attendees at the Intel's Developer Conference in San Francisco, "The Ultrabook is our vision that delivers the most satisfying and complete computer experience." [23]

The notebook PC supply chain is made up of a number of different players within the Notebook PC market. Intel supplies processors to their ODM and OEM customers. For PGA processors, when notebooks are assembled, ODMs create a bare board, and the final attachment of the CPU to the motherboard occurs at the OEM sites. For BGA processors, when notebooks are assembled processors are soldered directly to the motherboard at ODM sites.

2.2 Notebook PC Supply Chain Structure

Figure 3 shows who the players are, where they fit in the supply chain and the value that they deliver to the PC supply chain. Intel is one of many suppliers for components that appear on motherboards and is largely responsible for much of the product innovation that

[22] (Intel Corporation)
[23] (Otellini, 2011)

occurs in the supply chain. ODMs and OEMs largely add value to the market by providing efficient operations in order to deliver value to the market, and retail and resellers handle the customer relations to the actual customer.

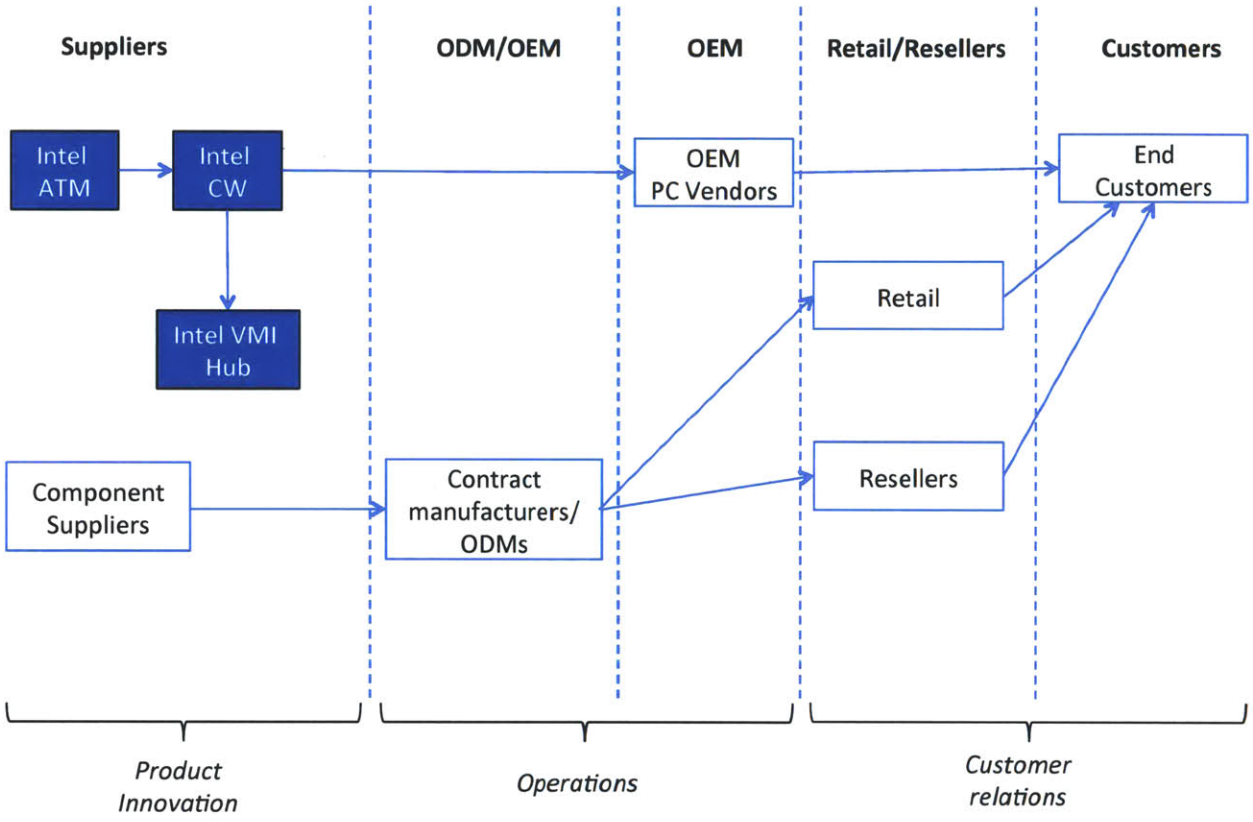


Figure 3: Notebook PC Supply Chain Overview[24]

As shown by Table 1 in bold, ODMs and OEMs face smaller gross and operating margins when compared with other companies in the PC supply chain. It is important that if Intel is committed to making Ultrabook™ mainstream, it must be committed to help ensure that its ODM and OEM partners are able to generate enough profit to sustain their businesses. ODMs and OEMs are primarily responsible for assembly and distribution, and their competitive advantages are primarily generated from the ability to effectively manage purchasing, marketing, and logistics. [25]

[24] (Foster, Cheng, Dedrick, & Kraemer, 2006), (Sailer, 2010)
[25] (Curry & Kenney, 1999)

Function	Supplier	Gross Margin (in %)	Operating Margin (in %)
Operating system	Microsoft	84.8	36.6
Processor	Intel	59.4	31.1
DDR SDRAM (graphics memory)	Hynix Semiconductor	37.3	24.9
Assembly	**Unknown**	**6.1**	**2.4**
Distributor	**Unknown**	**7.7**	**1.5**

Table 1: Profit margins from a typical Notebook PC (HP nc6230) in 2005[26]

2.3 Intel Roadmap Implications

Ten percent of notebook CPUs today are packaged in BGA and therefore soldered directly to the motherboard. Intel chipsets, which are chips that allow the CPU to communicate with other PC subsystems, have always been packaged in BGA. Historically, BGA CPUs have always been delivered in trays whereas chipsets have been delivered in tape and reel. Each reel holds hundreds to thousands of semiconductor parts so that pick and place machines do not need to be reloaded as frequently.[27] One tray tends to hold fewer parts than one reel and require more frequent reloading, which is helpful for replacing SKUs. There are many different reasons for the use of different carrier mediums for CPUs and chipsets shown in Table 2.

[26] (Dedrick, Kraemer, & Linden, 2009)
[27] (National Semiconductor, 2009)

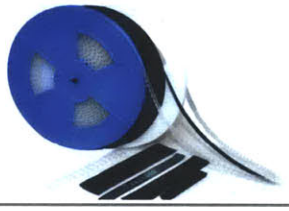
Chip Type	Ideal Shipping Medium	Reasons
BGA CPUs	Tray 	• High Product Mix • Ordered in smaller quantities conducive to trays
BGA Chipsets	Tape and Reel 	• Low Product Mix • Ordered in larger quantities conducive to tape and reel

Table 2: Ideal Shipping Medium for Various BGA Chips[28]

Intel has made a decision to transform the notebook industry by pushing the adoption of ultra thin and light notebooks known as Ultrabook™. In order to implement this new roadmap change, Intel is providing BGA CPUs instead of the normally used PGA package. Since BGA CPUs are connected directly to the motherboard (instead of via a socket like for PGA CPUs), the overall motherboard Z-height is decreased. Customers believe that there are efficiency gains from receiving BGA CPUs in tape and reel, because tape and reel is suitable for large volumes. Hence, the trend to ultra thin and light notebooks may lead to more customer requests for shipments in tape and reel.

2.3.1 Emphasis on Ultrabook™

Enabling the PC supply chain for Ultrabook™ involves enabling the supply chain with the designs and manufacturing capability needed in order to produce Ultrabooks™. Intel must have the ability to be agile in order to adjust to a fast paced market with constantly changing demand. One key factor to Intel's success involves the ability of Intel to enable its manufacturing partners to support creating Ultrabooks™. OEMs and ODMs will be burdened

[28] (ePAK International, Inc., 2008), (Texchem-pack, 2008)

with additional costs associated with producing Ultrabooks™, and based on their current margins do not necessarily have the resources to manage the mass production of Ultrabooks™. Without the support of its OEM and ODM counterparts, Intel will be unsuccessful in being able to enable innovation across the PC supply chain.

2.3.2 Customer motivations

It is essential for Intel to work with its customers so that they may both mutually benefit from changes that happen across the supply chain. While soldering BGA CPUs directly to the motherboard may improve the sales and reduce the height of one of the taller items on the motherboard, there are significant impacts to the ODM business model. Soldering a BGA CPU directly the motherboard has numerous implications including the reduction of SKU flexibility, inventory planning, rework, and other supply chain effects. [29] In order to promote Ultrabook™, it is important for Intel to find a way to alleviate some of the additional costs incurred in making systems thinner. In this thesis, we explore supply chain improvements that can increase the efficiency and decrease the cost for Intel's customers. Specifically, we investigate the potential benefit of Intel offering new carrier packaging to its customers.

Intel serves many different types of ODM/OEM customers of varying sizes. Where larger ODMs produce thousands of motherboards a day, Intel also serves a customer base that produces a few hundred motherboards per day. It is important for Intel to be able to serve both its large and small customers.

As volumes for BGA processors increase, OEMs will face many operational challenges including a ten times increase in the number of motherboard SKUs and and estimated doubling of service inventory cost.[30] Because there is a higher cost associated with manufacturing notebooks that contain BGA rather than PGA processors for Intel's customers, it is important for Intel to consider all the possibilities that can potentially improve the overall supply chain and help customers produce systems that contain Intel's product cost-effectively. By

[29] (Sailer, 2010)
[30] (Sailer, 2010)

decreasing costs for OEMs and ODMs, they may be more willing to produce more Ultrabooks™ and therefore increase the speed at which innovation happens throughout the supply chain.

3 Organizational Impacts

This chapter describes Intel's organization and the key stakeholders involved with the tape and reel decision process. With over 80,000 employees, Intel is a very large company. In order to run such a large business effectively, Intel has decision-making processes in place to ensure that the proper decision makers are involved, so that decisions are sufficiently analyzed and executed. For the company to innovate and keep up in today's rapidly changing market, Intel must be able to make changes that impact the entire supply chain and therefore multiple divisions throughout Intel.

3.1 Three Lens Analysis

The Three Lens analysis is a systematic way of examining an organization[31] and is used in this section in order to describe how Intel is run. The three lens framework consists of the strategic design lens, political lens, and cultural lens.

The strategic lens looks at the key processes that have been created in an organization to make key decisions and accomplish the goals of the organization. [32] In such a large organization, it is difficult to distinguish which groups are responsible for which requests, especially when the decisions impact multiple organizations.

At Intel, there are two processes in place that address issues that impact multiple groups. For high priority issues, corporate strategic decisions are issued, and these decisions usually come from upper management. For other major issues, cross functional teams are typically formed, and groups work together to gather data in order to drive upper level decisions. The creation of focused working groups allows requests to be serviced. These working groups can be thought of as tiger teams where the experts are gathered into one meeting.

Based on the strategic design of Intel, individuals at Intel within the organization may tend to have a view of a supply chain influenced by the group within the organization they work

[31] (Carroll, 2006)
[32] (Carroll, 2006)

in. Though the group may not be incentivized to make certain changes, positive impacts may be realized throughout the supply chain. With a decision such as deciding whether or not to offer customers tape and reel in addition to trays, offering tape and reel as an additional shipping medium impacts all parts of the PC supply chain. As a result of following protocols for making major decisions, major process changes must go through multiple approving bodies in order to be implemented. As shown in Figure 4 on Intel's side, the decision must be approved by various parts of the organization. Intel makes an effort to change this behavior by creating cross functional groups, but as with the tape and reel decision, how to form these groups with the proper stakeholders is not always clear.

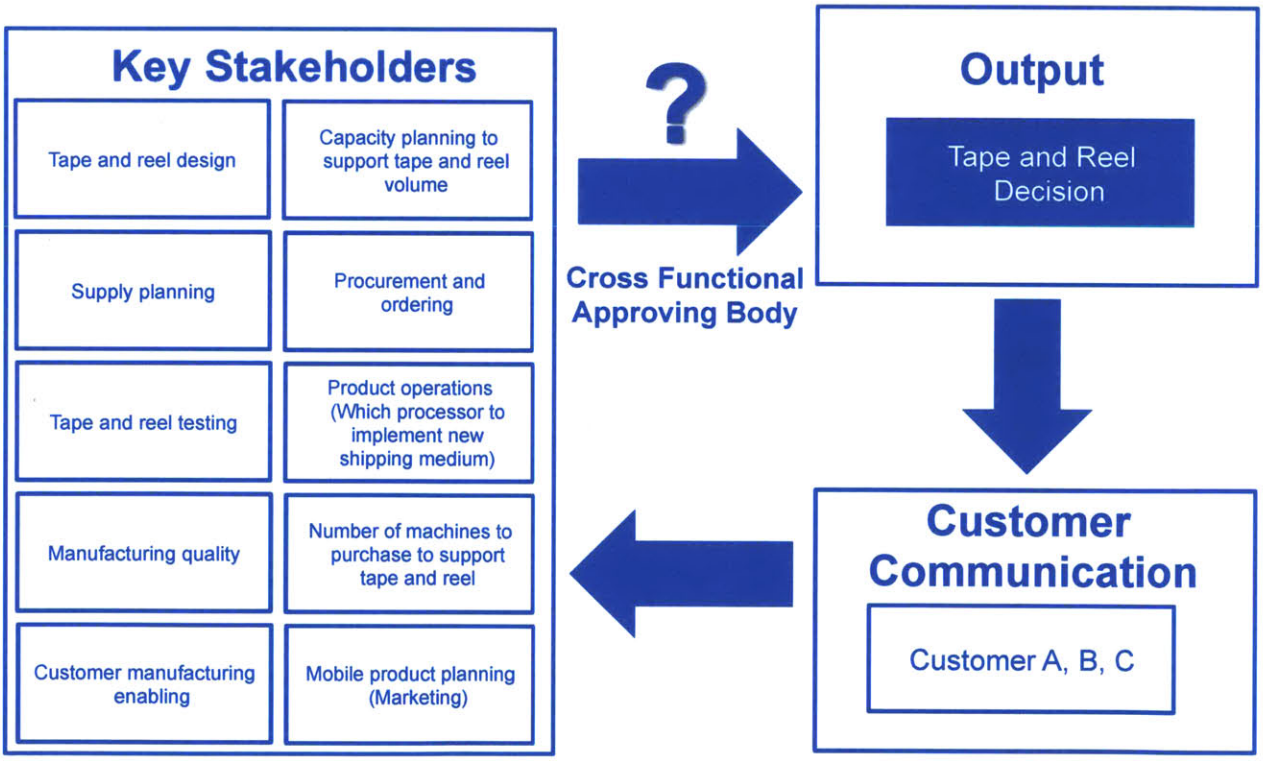


Figure 4: Organizational Impacts

Another side effect of the strategic design Intel employs is that while having processes in place ensures that decisions are well thought through, often the implementation of these processes and policies results in slow decision making and resistance from individual organizations. Groups within organizations will tend to resist change, because they may only

see how the change results in dedicating resources and putting investment into the change. However, it is possible that an investment from Intel across multiple groups sometimes may ultimately positively impact the entire supply chain. Another issue that often occurs in large companies is that sometimes it is not clear who has ownership of a change. For tape and reel, approximately ten groups are impacted, and it is not clear who owns the decision of whether or not to offer customers tape and reel in addition to trays.

Figure 5 shows where all the stakeholders fall within Intel's organization. One of the major oversights that could occur is that Intel may make the decision to make a certain change, but the change may cause short-term negative impacts before making an overall positive impact on the entire PC notebook supply chain. The tape and reel request has previously been raised and been addressed by many different groups throughout Intel but remained unresolved, because it was unclear whose responsibility it is to drive a recommendation from this project. Most groups are addressing their own high priority issues and are too busy to deal with this customer request, and because of how much this change affects different groups, most groups heavily resist the change. Furthermore, most of the impacted groups are concentrated in the Technology Manufacturing division and are not customer facing. Their priorities therefore may not be customer focused.

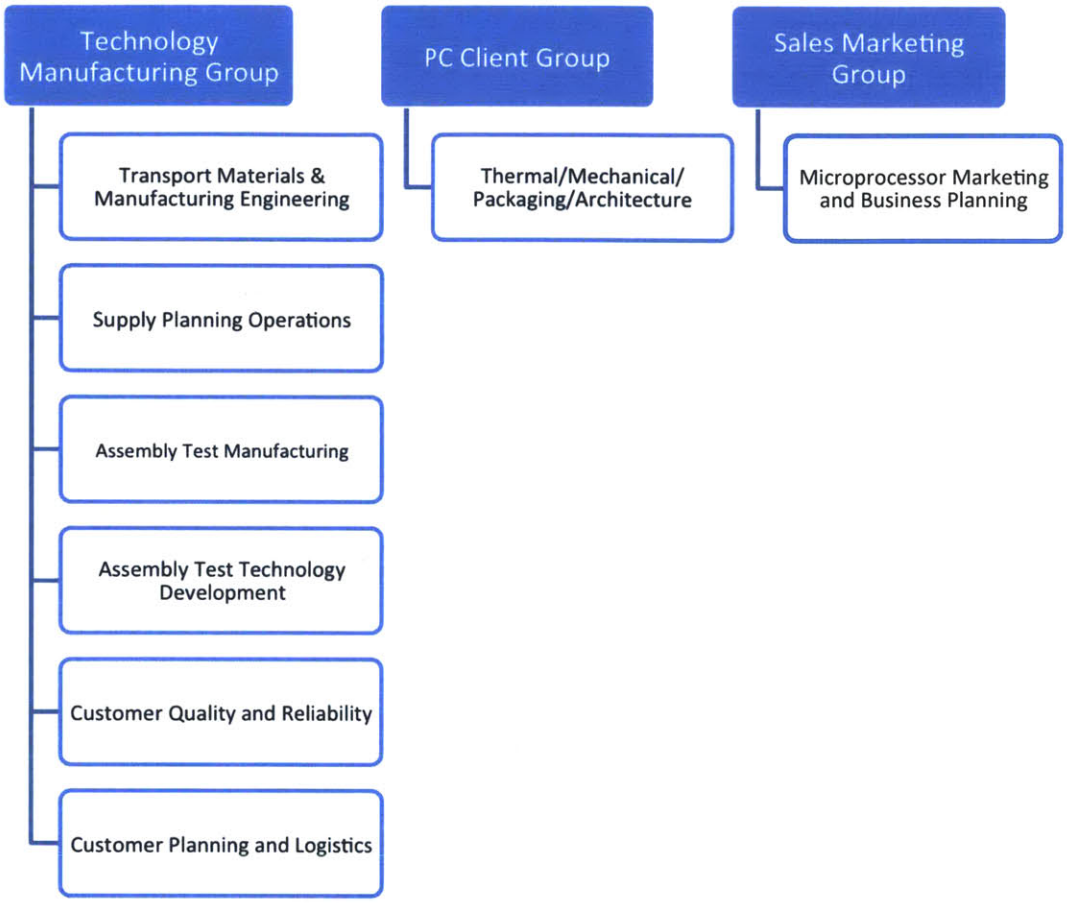


Figure 5: Intel's Organizational Structure

Though the strategic design dictates how decisions are made throughout Intel, *power* is second major component, which influences how much priority is placed on each decision. One way to analyze the power structures throughout Intel is by using the second, political lens in the three lenses framework. The political lens looks at which groups have power within an organization. Based on Intel's organizational structure and the structure of Intel's supply chain, there are examples where major changes were implemented that affected many different stakeholders. Through the political lens, though individuals have the ability to create change throughout the organization, upper management still tends to make the most important decisions including changes to the Intel roadmap and the creation of the VMI hubs. In the case of VMI hubs, many customers requested decreased lead-time. However, in the case of tape and reel, not all customers have made the request, therefore tape and reel is not a high

priority. Once more customers make the request for tape and reel, the priority may be escalated to upper management.

From a cultural perspective, the company is very data driven. A unique aspect of Intel's culture is how efficiently the organization can carry out a decision when presented with data that demonstrates how certain decisions will positively affect the company. Groups will initially resist change, but once it is proven that a decision will be beneficial for the company in the long term, groups will align to execute on a decision. One of the major changes that the company is undergoing is connecting different groups so that they are not silos and to encourage cross-functional cooperation and innovation. Intel has demonstrated its commitment to this change by holding a leadership conference sharing the message of the importance of working together across the entire company.

The tape and reel decision faces major challenges from both a political and cultural standpoint; however, should the decision ever become critical enough to the company the critical strategic decision forum would be an effective way to push the decision through. The decision would become critical at the point where Intel is able to get some kind of financial gain by implementing tape and reel or accelerate the adoption of BGA CPUs throughout the PC supply chain.

4 Tape and Reel and Tray Comparison

Tape and reel and trays are favored for different types of products. According to information obtained from National Semiconductor and other semiconductor manufacturers, they provide a variety of shipping mediums based on the products they are shipping. For shipping surface mount devices and BGA parts, they ship their products in tape and reel to simplify the way the semiconductors are handled on Surface Mount Technology (SMT) lines. Each reel holds hundreds to thousands of semiconductor parts so that pick and place machines do not need to be reloaded as frequently.[34] Tape and reel is effective for transporting and processing products with high volumes and low SKU complexity.

For a company such as Texas Instruments, trays are primarily used for low volume components and components that have "leads on four sides (e.g. Quad-Flat-Pack)."[35] Quad-Flat-Packs (QFPs) are a type of semiconductor packaging with applications such as programmable microcontrollers, programmable gate arrays, and linear/analog IC applications.[36] Trays are useful for being able to hold a small number of parts and protecting pin leads. They are also effective for transporting and processing products with low volumes and high SKU complexity.

Intel uses trays to ship its BGA CPU processors because of the large number of SKUs Intel provides to customers. Intel, unlike National Semiconductor and Texas Instruments, offers many more SKUs than these other companies so must take into account the added complexity of handling multiple SKUs. For this reason, Intel has traditionally used trays to transport its notebook processor products, because of the number of BGA CPU SKUs it offers in spite of the fact that it is technically feasible to ship BGA CPU processors in tape and reel.

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[34] (National Semiconductor, 2009)
[35] (Troxtell, O'Donley, Purdom, & Zuniga, 2006)
[36] (Materials Engineer, 2011)

4.1 Surface Mount Technology

In order to understand how ODM customer operations are affected by receiving a new shipping medium, it is important to have a basic understanding of the process of how a motherboard is populated with different components. This section describes the surface mount technology process and how tape and reel affects the surface mount technology (SMT) process. SMT is the process by which parts are mounted onto a printed circuit board. A typical SMT process is shown in Figure 6.

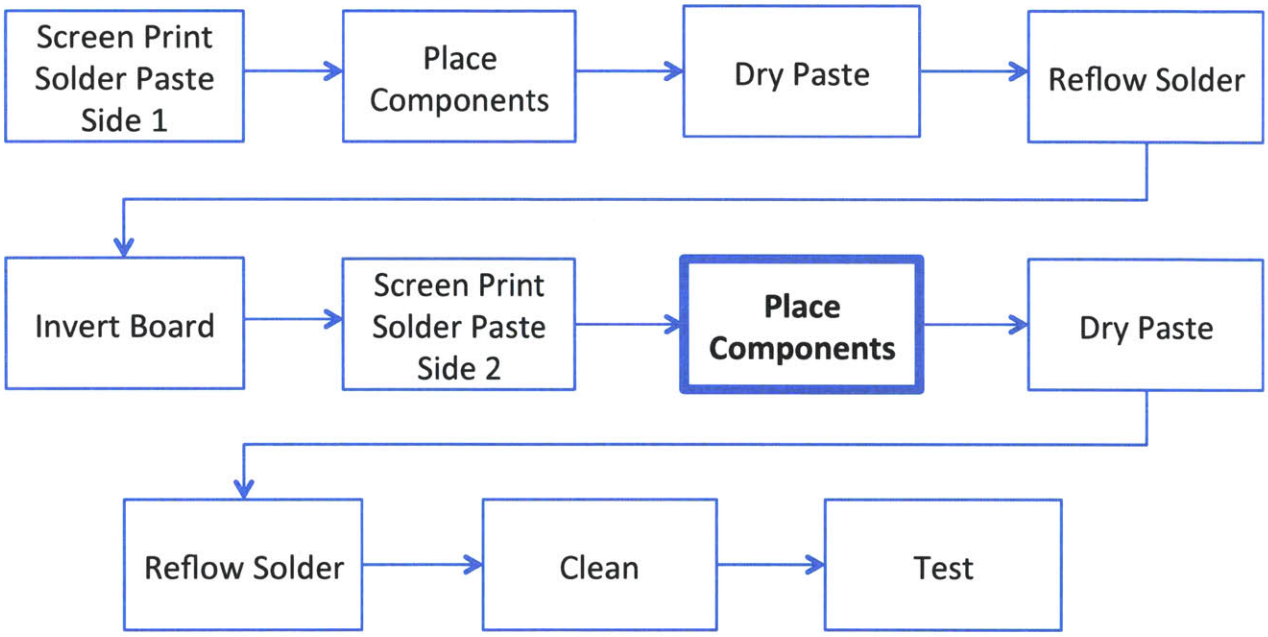

Figure 6: Typical Process Flow for Total Surface Mount (Type I SMT)[37]

The primary process that will be impacted on the Surface Mount Technology (SMT) lines by a shipping media change is the pick and place process. For customers, a major part of this investigation involves the benefits that customers receive along the supply chain. A number of suppliers who supply various motherboard components including resistors, capacitors, Ethernet chips, audio chips, connectors, etc., contribute to the number of parts that get attached to the motherboard. On the SMT line, these various parts need to be balanced across a line so that the productivity of the line is optimized.

[37] Figure adapted from (Intel Corporation, 2000)

There are two types of pick and place processes, which are the mid-speed pick and place process and the high-speed pick and place process. The mid-speed pick and place process is a high precision placement process for parts that have specific requirements for placement due to high pin count or other reasons. For the mid-speed pick and place process, pick and place machines are used in order to attach parts, such as processors, to the motherboard. The high-speed process is a low precision process for parts with fewer requirements for placement. The high-speed pick and place process utilizes a machine known as a chip shooter, which is used for attaching parts, such as resistors and capacitors, to the motherboard.

Receiving BGA CPUs in tape and reel impacts the mid-speed pick and place process by which the processor is assembled to the motherboard in the SMT process. ODM customers have dedicated pick and place machines to handle PC components in trays and dedicated pick and place machines to handle PC components in tape and reel. These pick and place machines are used to solder BGA CPUs to the motherboard.[38] Based on the way some customer lines are balanced, it was found that BGA CPU trays had to be replaced the most often during production implying an imbalance on their SMT lines.

4.2 Various Shipping Methods for Notebook Motherboard Components

Notebook BGA processors are shipped in various types of shipping mediums. As components have decreased in size over the years, tape and reel was created. Tape and reel makes it easier to handle parts on the SMT lines.[39] Handling is simplified, because, due to the large number of parts per reel, operators can replace reels less often while the SMT line is running. An example of a tape and reel is shown in Figure 7. As shown, a tape and reel is made up of cover tape, carrier tape, sprocket holes, an embossed cavity, and a reel. The sprocket holes are used to process the tape and reel through a machine. The bar code label area is used to determine which part is being held in tape and reel.

[38] (Intel Corporation, 2000)
[39] (Fairchild Semiconductor, 1998)

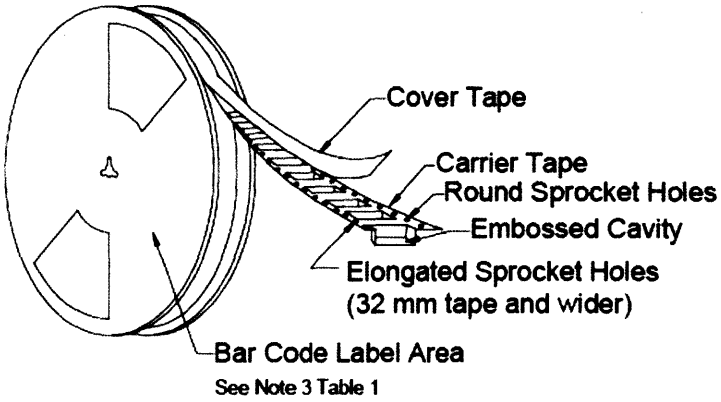

Figure 7: Tape and Reel[40]

Notebook motherboards have a number of components soldered down on the motherboard. Some of these components are shipped in reels and others are shipped in trays. Smaller components such as resistors, capacitors, chipsets, and a number of other components are generally shipped in tape and reel. Other components such as quad flat packs (QFPs), audio chips, memory chips, and processors are shipped in trays.

As volumes for smaller systems are increasing as Intel is following a strategy of moving the industry to higher mobility[41], BGA CPU volumes are expected to increase. With BGA CPU volumes increasing, it may make sense to ship BGA CPUs in tape and reel in addition to or instead of trays. The question is further described in Figure 8:

[40] (Electronic Industries Alliance, 2000)
[41] (Gartner, 2011)

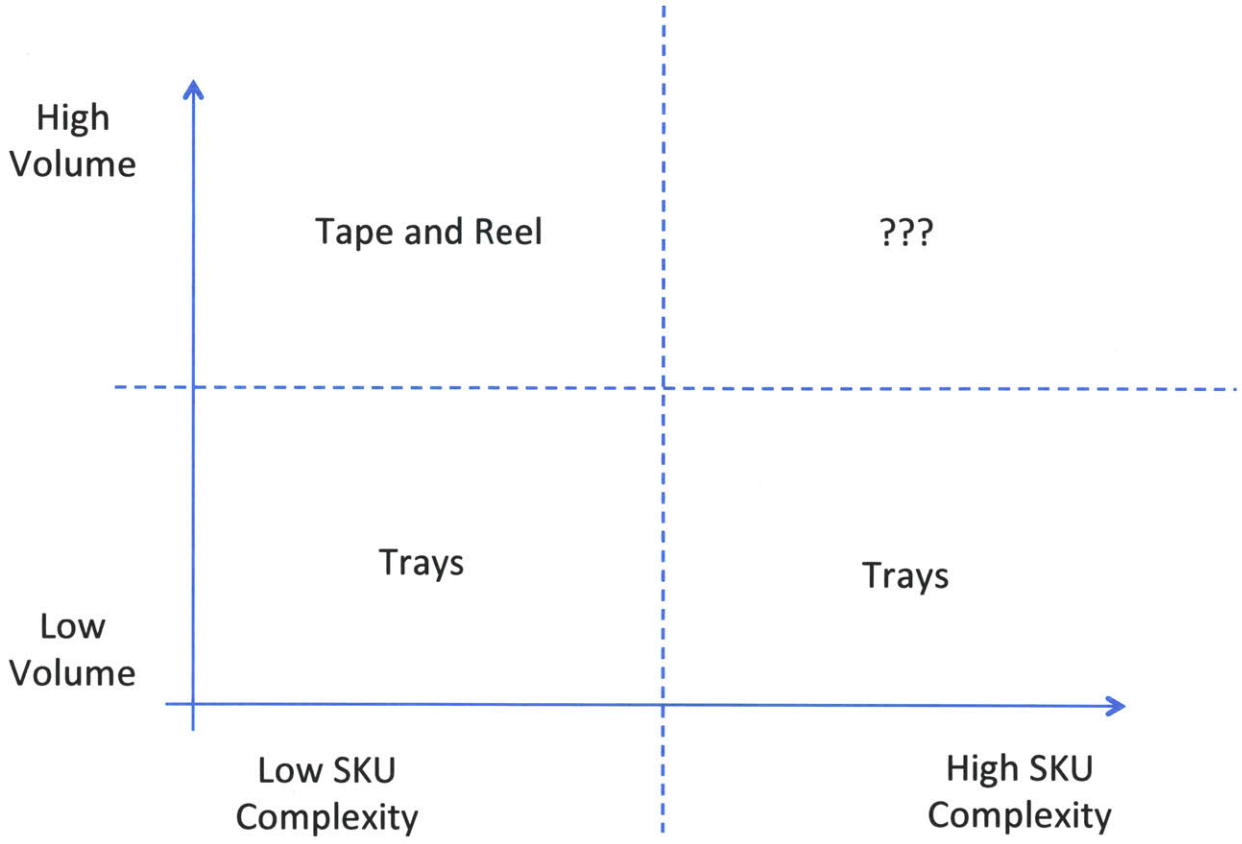

Figure 8: How to handle high volume and high SKU complexity

It is clear that the way to handle high volumes and low SKU complexity is with tape and reel; however, it is not clear what is the optimal shipping medium for a product with high volumes and high SKU complexity.

Customers are requesting to receive notebook BGA CPUs in tape and reel rather than in trays. As demonstrated by Fairchild Semiconductor and National Semiconductor, receiving BGA CPUs in tape and reel rather than in trays increases the speed at which the lines run and results in a decrease in labor and are impacts that Intel and the PC supply chain could potentially benefit from.[42]

4.3 Pros and cons of tape and reel

To date, Intel only offers notebook BGA processors in trays and its chipsets in tape and reel, because chipsets have a low SKU mix. The reason that Intel offers BGA processors only in

[42] (Fairchild Semiconductor, 1998)

trays is because Intel offers a wide variety of processors in trays. For other industry suppliers, as demonstrated by Fairchild and National Semiconductor, companies recognize that there is a labor savings component that increases the efficiency at which boards can be built if tape and reel is utilized.

The processors typically used in smartphones and tablets have been based on an architecture licensed from Advanced RISC Machines (ARM).[43] The companies that produce products based on ARM typically ship those devices in tape and reel with quantities of 1000. One example can be found on Digikey, which is a website that sells electronic components. The ARM Cortex produced by Texas Instruments is sold in quantities of 1000 and shipped in tape and reel.[44] It is very common for mobile products to be shipped in tape and reel, because these products tend to be smaller and fit a significant quantity on a reel, and so parts can be processed much more quickly.

4.4 Pros and cons of trays

In contrast, trays are very efficient for products that have many different SKUs, with volumes split over multiple flavors. The major issue with tape and reel is that there is very little flexibility for ordering quantities and can therefore lead to difficulty managing and planning inventory.

[43] (ARM, 2012)
[44] (Digi-Key, 2012)

5 Methodology

This chapter describes the methodology that is employed in order to determine whether or not it is feasible or cost efficient for Intel to provide customers with tape and reel. An approach is used to challenge assumptions from both Intel's side and the customer side in order to determine whether or not offering tape and reel is feasible based on interviews and financial cost information.

The first step is to conduct an initial showstopper analysis by conducting interviews with stakeholders within Intel to identify technical implications involved with tape and reel and estimate costs. The initial showstopper analysis involves a qualitative analysis, where different groups are interviewed. From the initial interviews, we identified key issues internal groups would have to overcome in order to provide tape and reel. From the initial showstopper analysis, we found no technical showstoppers that prevented Intel from offering tape and reel, which was unsurprising since Intel already offers chipsets and other components in the tape and reel format.

Following the initial investigation, each stakeholder conducted a financial assessment of the additional costs involved with tape and reel. We also identified how many parts would be on a reel in comparison to how many parts would be put on one tray. The number of parts per tray was estimated to be approximately twenty parts in comparison to two hundred to four hundred parts per reel.

5.1 Customer savings

After interviews were conducted within Intel, we conducted a number of surveys prior to visiting ODM factories on site to interview SMT line factory managers. We identified three of Intel's ODM customers as being the most likely to benefit from receiving BGA CPUs in tape and reel. These customers are all very large, are producing some number of BGA processor powered notebooks, and have requested receiving BGA CPUs in tape and reel in the past. These customers will be referred to as Customer A, B, and C, and a summary of the interview

findings are described in Table 3. They were asked questions about different aspects of their SMT lines including:

- Carrier packaging needs for different parts of the product life cycle, which is made up of three stages: New Product Introduction (NPI), High Volume Manufacturing (HVM), and End of Life (EOL)
- Tray Pick and Place Machine Capacity
- Savings generated from tape and reel
- Motherboards processed per day

ODM Customer	Key characteristics
A	• Benefit the most directly from tape and reel due to lack of tray pick and place machine capacity • Customer put the most time into calculating efficiencies • Fully calculated SMT line benefits from switching to tape and reel
B	• Unable to switch carrier packaging when switching from trays to tape and reel from NPI to HVM, because in NPI trays many different CPU SKUs are handled on the same line (which requires trays to switch out smaller quantities) whereas in HVM each line is dedicated to one SKU (which can be processed in tape and reel, due to bulk processing) • Since chipsets have low SKU complexity, tray flexibility is not needed • Requires being able to work with small quantities in NPI
C	• Minimal savings from tape and reel • Company has not had as much Notebook BGA volumes • Specific ODM customer works with very small OEMs

Table 3: ODM Customer Interview Key Findings

The goals of the interviews were to verify the efficiencies they thought they would gain from tape and reel and discover whether or not there were unintended consequences from receiving BGA CPUs in tape and reel. Based on the interviews, ODM customer savings overall on the SMT line from tape and reel are surprisingly minimal. We discovered that each customer does not benefit from tape and reel in the same way. From visiting Intel's customer

sites, there are a number of issues that make it seem like there is a large savings to be gained by switching over to tape and reel; however, upon deeper analysis, both Intel and the ODM customers realized that there might be less savings than first proposed. It was found that on certain customer SMT lines:

- The stage where pick and place occurs for BGA CPUs was not always the bottleneck in the overall line, because of the way various customer SMT lines are balanced.
- Customer feedback was not consistent across the different large ODMs as to how much receiving BGA CPUs would be helpful to them on the line.
- The extra efficiency gained on the lines was relatively low for all customers from both a headcount and machine savings standpoint.

5.2 Cost vs. Benefit

After data was collected from ODM customer SMT line managers and stakeholders within Intel, we compiled the data in a cost-benefit analysis. We found that the expected overall supply chain savings are not realized. Intel will have to make a significant investment in order to offer tape and reel to customers. With little to no benefit for the customers, and only costs incurred by Intel, there does not seem to be enough overall benefit to motivate adding tape and reel. Therefore, we recommend that Intel not offer tape and reel in addition to trays. As evidenced by both the internal and external cost assessments, the ODM customers will not gain enough benefit from tape and reel to deliver overall savings to the PC supply chain based on current conditions.

6 Customer efficiencies

As part of the investigation to understand how offering tape and reel would add value to the PC supply chain, we examined to what extent customers would benefit from tape and reel. There were three major aspects we explored including: machine efficiencies, headcount efficiencies, and inventory efficiencies. For each of the major aspects, we found that customers enjoyed only minimal efficiency gains from employing tape and reel.

While ODM customers may enjoy minimal machine and operator efficiencies, OEM customers will be unable to control inventory effectively. OEMs are responsible for procuring BGA processors from Intel and pay to hold inventory at ODM sites. We found that based on OEM customer ordering patterns that customers often hold small amounts of inventory per each SKU during New Product Introduction (NPI), because only a couple hundred parts per each SKU are used daily at ODM sites. Because of this behavior, parts must be ordered in tray form during NPI to maintain flexibility on the line by allowing SKUs to be changed on each line. However, it is unclear at what point OEMs should switch from ordering trays to ordering tape and reel. In addition, small OEMs order very small quantities of processors, and due to the high value of processors would be unable to ever order enough BGA processors to justify using tape and reel.

Customers initially thought that they would see a great increase in efficiency on their SMT lines from receiving BGA CPUs in tape and reel; however, the reality is that there are still other motherboard components that are shipped in trays. For certain customers, the tray machine was not a bottleneck on their SMT lines and they would actually have no savings on certain SMT lines.

6.1 Machine efficiencies

As part of the investigation for machine efficiency, we determined whether or not customers would actually be able to benefit from the increased speed from tape and reel. When customers run their tray machines, the machine doors must be opened, and the entire SMT line must be stopped in order to replenish trays to continue running the line. The line

therefore must stop running during that time decreasing the efficiency of the overall factory. In contrast, tape and reel holds a larger quantity of chips reducing the number of changeovers they would have to handle, and each line could run continuously.

Though these initial claims seemed valid, we sought to understand if the number of Intel's SKUs could impact the supposed efficiency gain by receiving BGA CPUs in tape and reel. However, it was found that large ODMs process thousands of motherboards each day during high volume manufacturing and therefore have enough volume to dedicate an entire SMT line to one SKU. For this reason, different BGA CPU SKUs are generally not used on the same line, therefore no time would be lost on the line due to CPU reel changeovers. However, though the benefit would be realized during high volume manufacturing, one issue that was not consistent across the different customers was how to address the issue of changeovers during new product introductions and refresh cycles where very small volumes are handled.

6.2 Operator efficiencies

One of the major benefits of receiving BGA CPUs in tape and reel is due to the fact that reels hold more parts. Subsequently, fewer operators are needed to run these machines. Through customer interviews, we investigated how much operator efficiency was gained by receiving the new shipping medium. From visiting the factories, we found that regardless of whether Intel's BGA CPUs are in tape and reel or trays, an operator must still be running the pick and place machine for trays. The reason that an operator must still be running the tray pick and place machine is because there are still other components (such as QFPs) that are currently being shipped in trays today. Other components that are still in trays include certain audio and Ethernet chips. Given that an operator still needs to run the tray machine, the maximum savings each line would receive is 50% of the tray pick and place operator's time to do something else such as replenish materials.

6.3 Inventory efficiencies

One issue that ODM customers did not identify in their request was the effect of receiving BGA CPUs in tape and reel on inventory. We identified inventory holding time an area

of concern, because it takes a longer time to process an entire reel than it does to process an entire tray due to the standard number of parts per each shipping media. The time it takes to process an entire reel is important, because semiconductors are moisture sensitive parts. Moisture can be absorbed into the parts if exposed to the air for too long. This is an issue because excess moisture in the parts gets vaporized when heated during the solder reflow process, which can cause problems with soldering. Both tape and reel and trays are stored in moisture barrier bags. Once these bags are opened, they no longer protect the CPUs from moisture.

There are two ways to protect CPUs from moisture: one method is preventative and the other is responsive. To prevent moisture from accumulating, unused parts can be stored in ovens at the end of each day. To remove moisture after parts have been exposed for too long, baking, the process of exposing parts to high temperatures, can be utilized. Baking can only be used if parts are stored in trays. Tape and reel can theoretically be baked, but because tape and reel has a lower melting temperature than trays, the parts need to be baked at much lower temperatures. As a result, baking times for tape and reel are not practical.

To understand if there are any inventory efficiencies gained by receiving parts in tape and reel rather than in trays, we first examine how different customers move inventory across their factories. Customers have material handlers across their factories that move processors in unopened moisture barrier bags that hold BGA CPUs from storage to the SMT lines. Operators on these lines receive the bags, then, they open the moisture barrier bags. At this point, processors are exposed to moisture. If all the processors are not attached to the motherboard within a day, these parts are moved to large ovens where reels or trays can be stored overnight if the entire bag is not used over the course of production.

Through interviews, we found that ODM customers were not concerned with inventory storage or issues with moisture. As mentioned, tape and reel cannot be baked at temperatures as high as that of trays; however, the baking should not be necessary, because there are many storage ovens available to store parts that are not used on the SMT line within one day. ODM

customers currently have sufficient storage oven capacity throughout their factories if tape and reel were implemented.

7 Technical and Operations Implementation for Intel

This chapter describes the processes that must be completed in order for Intel to fully implement tape and reel throughout the company. Table 4 shows an overview of all the different parts of Intel's supply chain that are affected by offering tape and reel and the varying degrees of severity defined by the costs involved to support tape and reel. Low risks are shown in green, medium risks are shown in yellow, and high risks are shown in red. The risk is defined by the factor either having a high impact on cost, resources, schedule, or engineering. As demonstrated by Table 4, the highest risks come from managing the SKU doubling that would result by offering tape and reel to customers. The middle column describes technical and financial impacts of offering tape and reel, and the tape and reel and tray column represents the logistical challenges from offering tape and reel and trays.

Assessment Areas	Tape and Reel (Only)		T&R and Tray
	Technical	Cost	
T&R Design	Reel Design	Material Costs	N/A
Factory Process Flow	Reel Design	SKU Doubling / Inventory Growth	Additional Logistics and Handling
Packaging into T&R	Factory layout/ Capacity/ Flow	Equipment	Additional Logistics and Handling
Freight/Storage/ Shipping	Fragility	Higher Shipping/Storage because of packing density	Additional Logistics and Handling
Traceability	Individual CPUs on T&R more difficult to scan	N/A	Customer Ordering Flexibility

Table 4: Tape and reel showstopper analysis

Based on the analysis from Table 4, there were no known showstoppers found that make Intel unable to ship BGA CPUs in tape and reel from a financial and technical standpoint. The key finding from the showstopper analysis was that tape and reel would have to be offered in addition to trays for two reasons:

- Small quantities ordered during New Product Introduction
- Small OEM customers that produce small volumes

The biggest complication arises from the increased SKU complexity of offering tape and reel in addition to trays. Intel ships its chipsets in tape and reel, so the company is familiar with the processes to ship products in tape and reel. Though there are many issues that the company would have to work through, it is still feasible for the company to make an investment in tape and reel and allow their processors to be shipped to customers. The biggest risk that Intel would take in shipping products in tape and reel is the ability of Intel to manage its own SKUs.

Based on the showstopper analysis, there are four main processes that must be complete in order to fully implement tape and reel as shown in Figure 9. These four processes from the top of the figure to the bottom of the figure include: tape and reel development, capacity planning as it relates to capital expenditure, warehouse processing development, and major Information Technology (IT) system changes. Intel's IT system is made up of all of the software used to track orders and parts throughout Intel's supply chain. Based on the cost benefit analysis for tape and reel, the biggest issue for Intel is how to manage offering both tape and reel and trays in its IT system, which was brought up as a concern by multiple groups. For other components such as chipsets, trays are only used for engineering samples. All other parts are shipped in tape and reel, and customers have no problem ordering large quantities of chipsets due to the lower cost for customers to order chipsets rather than CPUs. In addition, due to the fewer number of SKUs offered, most of the parts are likely to be used and not become obsolete.

Companies such as Advanced Micro Devices (AMD) and ARM offer their BGA CPUs in reels, because they offer fewer SKUs than Intel. Intel is for the first time exploring delivering their smartphone microprocessors in tape and reel and trays. The group is only doing this because the SKU complexity is low and smartphone processors have traditionally been delivered in tape and reel. Since Intel's IT system currently does not support the ability to differentiate between tape and reel and trays, Excel spreadsheets are used to manually track parts.

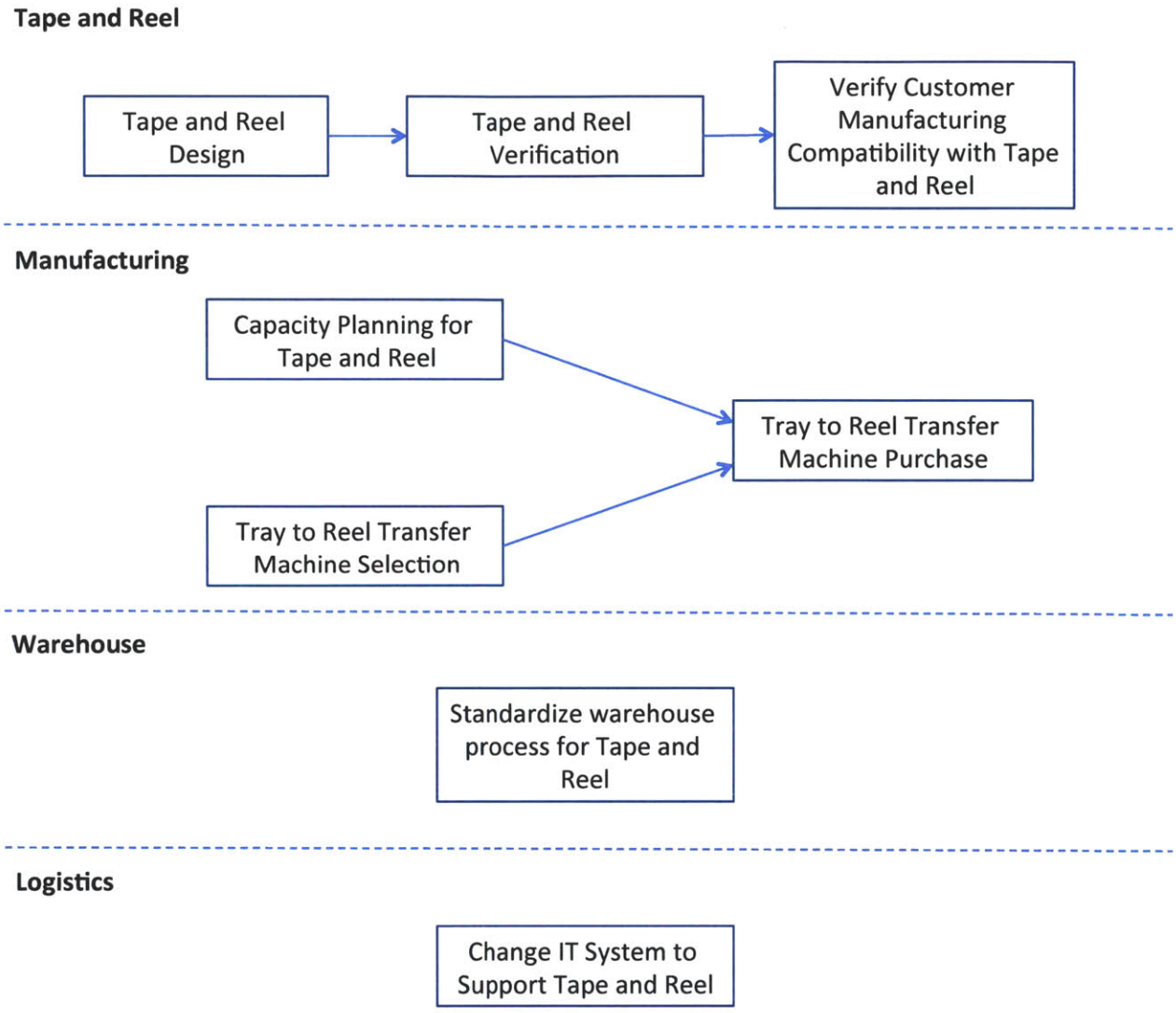

Figure 9: Intel Process to Offer Tape and Reel

7.1 Intel tape and reel development process

One of the main processes that must be completed is the tape and reel development, which includes design, verification, validation, and fragility qualification of the tape and reel design. Interviews were conducted with engineers from the Engineering and Operations group in the Customer Planning and Logistics division within Intel to understand this process. The tape and reel development process is a low risk process that is currently being used for Intel's chipsets.

The reel design process begins once the final package design of the BGA CPU processor is finalized. The reel design dimensions are based on the dimensions of the BGA CPU processor. The reel design determines how many parts go in each reel following the Electronics Industries Alliance (EIA) standard. EIA seeks to establish standards between manufacturers and purchasers to help improve products and allow for interchangeability between different products. The design requirements in Figure 10 show definitions for how precise the measurements for the embossed cavity must be for the part to fit in the hole properly to meet EIA standards.

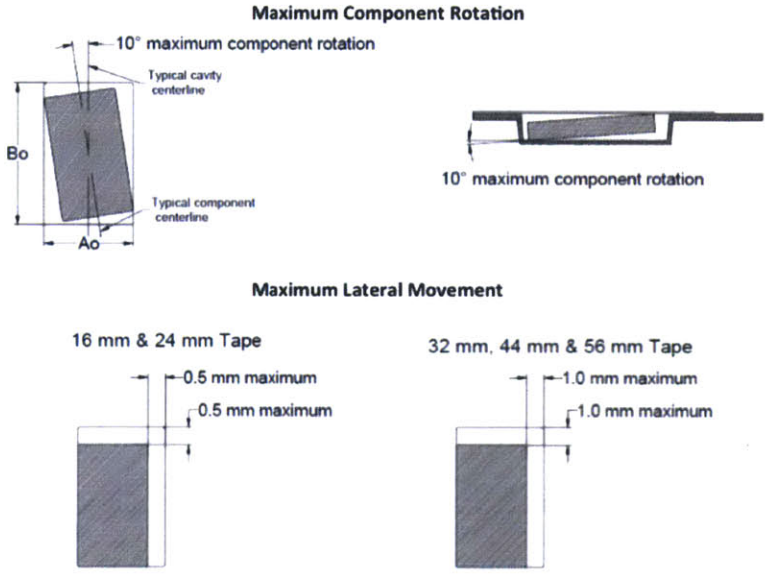

Figure 10: EIA Tape and Reel Design Requirements[45]

The requirements for tape and reel are sent to a tape and reel supplier, who sends back initial designs for verification. If verification finds any issues, the tape and reel designer makes the appropriate changes and sends out the design to the tape and reel supplier. The process is iterated until the design is finalized and validated.

Following the design of tape and reel, the initial design goes through a fragility qualification process. Because the fragility qualification process has been used for other parts produced by Intel, fragility is a low risk issue. Intel qualifies carrier packaging with real

[45] (Electronic Industries Alliance, 2000)

packaged parts and tests for fragility through three tests: vibration testing, shock testing, and force testing. Shipping BGA CPUs in tape and reel could result in additional padding needed in order to protect the BGA CPUs during shipping, which is known as overpack, and results in additional carrier packaging costs. Overpack is usually required when there are capacitors soldered onto the top of a chip package. Based on this requirement, fragility testing is a standardized process that is seen as a low risk when deciding whether or not to ship BGA CPUs in tape and reel. The process should be easy to implement; however, customers also perform their own testing and validation at the system level.

7.2 Machine selection and capital expenditure

In addition to new material carrier packaging, a new machine must be added to the end of the BGA CPU production flow to transfer the BGA CPUs from trays to tape and reel. In order to understand how Intel's manufacturing line is affected by the addition of tape and reel, it is necessary to have an understanding of Intel's assembly test manufacturing process, which is shown in Figure 11. The substrates, which are delivered to Intel in trays, are delivered from Intel's supplier in injection-molded trays and are transferred to carrier trays. Carrier trays are used throughout the assembly test process until the Finish process where processors are inspected and transferred from carrier trays back into injection-molded trays for shipping. In order to transfer the BGA processors from trays to tape and reel, a new machine must be added to the Finish process for carrier tray to tape and reel transfer.

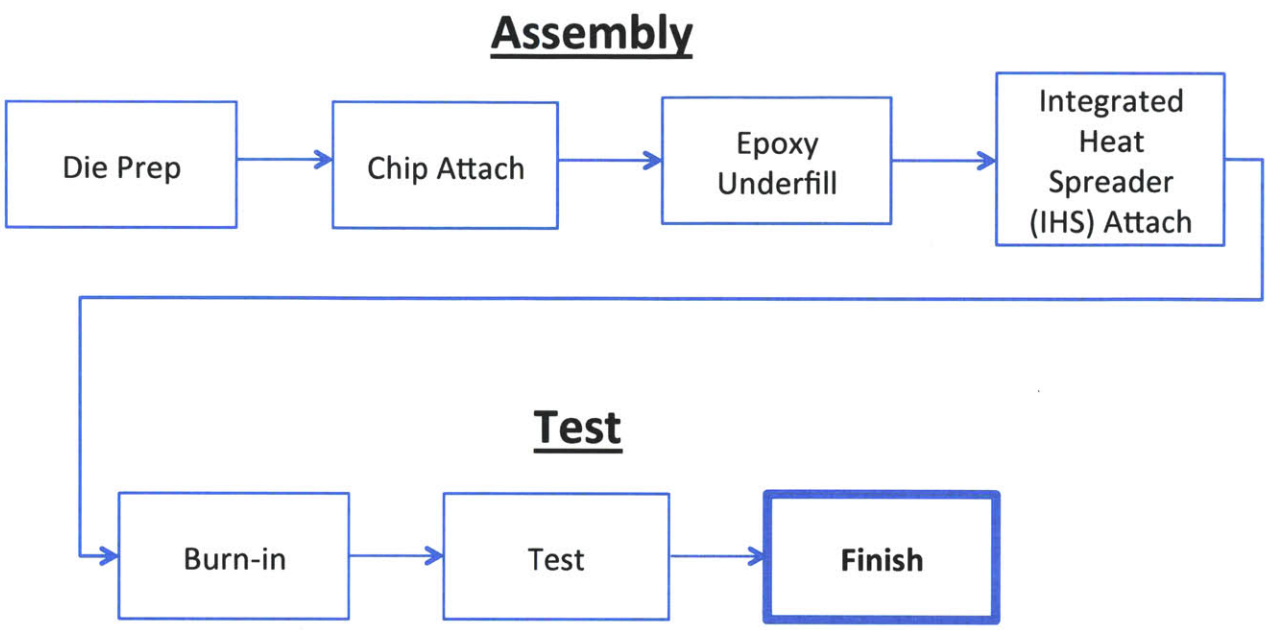

Figure 11: Intel Assembly Test Process[46]

New machines must be purchased in order to perform tray to tape and reel transfer. We used demand forecasts in order to determine how many tape and reel transfer machines must be purchased to support the demand for notebook BGA processors in tape and reel. We conducted this analysis by using projected volumes for 2013 in order to determine how many machines would be needed if Intel were to ship 100% BGA CPUs in tape and reel. 100% BGA CPUs in tape and reel is an unlikely scenario; however, for the cost-benefit analysis the worst case cost is evaluated.

For Intel's machine selection, capital expenditure that will result from shipping BGA CPUs in tape and reel is expensive, but not so expensive that it should stop Intel from offering BGA CPUs in tape and reel to its customers. The machine is familiar, because the machine used will be the same machine used to package chipsets in tape and reel. In addition, these machines will not have added inspection capability, so the cost to Intel though high would not be any reason to not alleviate some costs for customers.

[46] (Zurin, 2006)

7.3 Shipping optimization

By shipping parts in tape and reel, there are a number of shipping inefficiencies that result from shipping parts in tape and reel rather than in trays. The main reason for the inefficiency is because tape and reel is less space efficient than trays due to the dead space that is located in the center of the reel. In order to optimize efficiency, the more parts on a reel the more efficient the packaging will be. However, due to weight limitations of the reel on the manufacturing line and the maximum number of parts that can be on a reel due to fragility considerations, there is an optimal number of parts that should go on a reel by design. Too few parts on a reel will result in too high of a cost for shipping. In addition, if the number of parts per reel does not far outweigh the number of parts in a stack of trays, then the benefit is reduced. Shipping parts in tape and reel will result in two major issues: shipping costs as well as warehouse costs will increase. Should the parts require overpack, shipping costs would increase even more.

7.3.1 Warehouse

One of the major processes that would need to be overhauled in order to support tape and reel include creating a standardized warehouse process for BGA CPUs in tape and reel. Intel currently has many standard processes for handling its BGA CPUs in trays including a partialling procedure used to handle trays with quantities less than the full tray. Partial boxes can be combined with full trays and boxes or split to match the exact customer order quantity. New processes need to be put in place to support the process to move BGA CPUs in tape and reel through the supply chain. One of the major services that Intel offers to its customers is the option of partial trays. Intel allows its customers to order BGA processors in minimum order quantities of one. With tape and reel, Intel will be unable to support this service for customers, as BGA CPUs will have to be ordered in standard reel quantities. As mentioned in previous chapters, Intel serves a diverse customer base, servicing customers of various sizes. The importance of being able to order parts one at a time is very important for smaller customers who do not have the cash to support holding large inventory for Intel's very expensive processor.

In addition, Intel will have to account for warehouse space efficiency considerations that are not taken into account for trays. From a capacity standpoint, tape and reel is less efficient than trays; tape and reel dead space in the middle of the reel takes up approximately 1.5 times the space that trays do. Given this estimate, capacity for Intel's warehouses would have to increase. The bigger issue from a warehouse standpoint is the process and IT system that supports tape and reel. Tape and reel processes would have to be done in parallel to tray processes, which creates the additional complexity of managing both. The new processes would require customers to order minimum order quantities with tape and reel, which is an issue they do not have to address today given that their minimum order quantity today is one part.

7.3.2 Shipping

Shipping costs are measured by either the maximum volume that the package takes up or the weight of the freight. The maximum cost of the two is taken in order to evaluate the cost of shipping. CPUs are distributed by air, and because they are distributed by air, the costs of shipping CPUs in tape and reel is more than when shipping trays. However, Intel's chipsets, a lower cost part, are shipped in tape and reel, so this cost consideration is likely not a driving factor for why BGA CPUs are not shipped in tape and reel.

7.4 BGA CPU demand forecasting and handling processes

The final and most important issue that Intel must be able to address in order to support tape and reel is the issue of additional handling and logistics. We interviewed Intel's Logistics and Planning group in order to understand the changes that would need to be made in order to support tape and reel. Two major issues that arose from adding an additional shipping medium are: resolving the issue that trays and tape and reel hold a different number of parts, and handling double the number of SKUs.

Trays and tape and reel have different standard quantities. Trays today hold approximately twenty parts whereas tape and reel hold between two hundred to four hundred parts. Especially in high volumes, customers still tend to order in mostly full tray quantities. In

order to support two different shipping mediums, Intel must modify its current IT system to support different standard quantities and track which part is in which medium. Today, Intel's IT system is inflexible and is unable to support both trays and tape and reel. Since BGA CPUs are primarily shipped in trays, all the standard quantities in Intel's IT system is customized for trays. At VMI hubs, Intel limits customers to being only able to order BGA CPUs in standard order quantities. However, if customers order from the main warehouses, customers are permitted to order a minimum order quantity of one. Intel uses standardized increments throughout its supply chain, including at its VMI hubs; there are different standard quantities required at different VMI hubs where partialled trays are not permitted. In order to address this issue, Intel would have to overhaul its IT system in order to effectively service its customers, because the standard increment currently built into the system would not support the new standard increment that would be required by tape and reel.

The highest risk factor involved with delivering BGA CPUs in tape and reel is the ability of Intel to support the number of SKUs doubling for each of its mobile products. There is currently no standard way to process BGA CPUs in tape and reel in the warehouses. In addition, Intel would have to be able to forecast which products are packaged in tape and reel and which products are packaged in trays resulting in added complexity for demand forecasting. Given the way that the IT system works, Intel must overhaul the entire system, which would take significant headcount and resources to implement.

8 Key Findings

The key findings were based on the current state of the PC supply chain today and assume:

- Projected 2013 BGA volumes with BGA volumes expected to grow to 40% by 2013
- Other components are still shipped in trays
- Low wages in China; factories are moving inland
- OEM procurement policies when switching over to BGA will be similar to historical ordering patterns
- Customers will still require receiving BGA CPUs in both tape and reel and trays
- Customer factories are not running at capacity
- A constant tray to tape and reel transfer machine price
- Pick and Place tray loading matrix machines are inexpensive

Intel incurs a high cost from switching over from trays to tape and reel throughout the PC supply chain. As shown in Table 4, there are a number of factors that increase costs to ship the notebook processors in tape and reel. The majority of the cost comes from shipping BGA CPUs in tape and reel.

8.1.1 Cost-benefit analysis

A cost-benefit analysis was conducted in order to determine the costs and benefits associated with tape and reel for both Intel and the customer. The additional costs needed to support tape and reel were calculated to determine how much of a cost there would be in addition to trays. For the purposes of this thesis and proprietary reasons, sample data is used in this thesis to demonstrate the cost-benefit analysis procedure. The following sample data is listed in Appendix B and will be used for all subsequent calculations. The sample data does not in any way reflect the actual data that was used during the internship. Cost data was normalized on a per unit basis based on the forecasts.

A number of factors were considered when determining the costs and savings associated with tape and reel. Assumptions that were made for the cost benefit analysis included:

- 100% volumes in tape and reel
- Only full reels are permitted
- Between 240 – 360 parts per reel

8.1.2 Intel Cost Equations

From Intel's standpoint, the costs of offering tape and reel are significant. The key costs include additional material costs, logistics costs, capital expenditures, and IT system change costs. The greatest of these costs are in the IT system change costs that are involved. In order to calculate logistics and material costs, we used the equations found in Appendix C under Section 1.[47] The additional reel material cost for tape and reel is the entire cost of the reel without subtracting any of the costs of trays, because trays still need to be purchased in order to bin parts throughout Intel's factory.

In order to calculate the costs of capital expenditure, we calculated the number of tape and reel transfer machines based on the number of machines needed to support peak volumes. The equation found in Appendix C under Section 2 was used in order to determine the capital expenditure per unit.[48]

We determined IT system change costs by the headcount needed in order to support the additional tape and reel SKU. The headcount was provided by the Customer Planning and Logistics Group and did not take into consideration system change costs. The additional headcount provided in this thesis is sample data only. The equation from Appendix C under Section 3 was used in order to determine the cost of handling for additional SKUs.

[47] (Package Engineer, 2011)
[48] (Finishing Module Engineer, 2011)

8.1.3 Customer Benefit Equations

Based on customer interviews, we found that the benefit they receive is not significant. The areas where there should be increased efficiency include from an operator headcount and increased beat rate. However, upon deeper investigation, neither machine savings nor headcount savings is significant. The reason that neither of these issues significantly impact is because there were a number of factors not taken into consideration.

During surveys and interviews, customers provided information about their tray beat rate (the number of boards they produce per day per line), the number of lines in each of their factories, and the time savings per board they receive from receiving BGA CPUs in tape and reel. This information was used in order to calculate machine savings and assumes that the BGA processor pick and place process is the bottleneck on the line. The formulas used for calculating customer machine savings can be found in Appendix C in Section 4. These formulas represent the maximum beat rate that the factory can achieve by utilizing tape and reel by calculating the tape and reel beat rate. Assuming that 30% of volumes go through one of the large ODMs, we used the equations found in Section 4 to determine how many additional machines would need to be purchased in order to achieve the same beat rate for trays as for tape and reel.

Through customer surveys and from line visits, customers provided information that was used to compute the additional headcount efficiency gained by receiving parts in tape and reel. The information provided included the number of parts per tray in the next limiting item and the number of slots in the tray pick and place machine dedicated to Intel BGA CPUs. Through customer interviews, customers identified QFP chips as one of the other components on the motherboard that is shipped in tray carrier packaging. Approximately eighty QFP chips are on each tray, and each of these QFPs has many different varieties. Assuming 20 BGA CPUs per tray, the next limiting item is the QFP chip. It was found that there would be one additional slot made available for each of the QFP parts. The formulas used for calculating the headcount efficiency gain can be found in Appendix C in Section 4. Based on the new number of operators required to run the tray machine, the number of new operators can be multiplied by the

number of lines and by the time savings gained from machine savings, therefore providing a new number of operators needed to run the line.

8.1.4 Sample data solution based on formulas

Utilizing the formulas that are defined in Appendix C, from both Intel's and the customer's standpoint, the following methodology was used in order to compare the cost and benefit both parties would receive. Based on the equations shown in this section and values from Appendix B: Sample Data, the values in Table 5 give an example of how much of an investment it will be to offer tape and reel for Intel and savings for the customer:

		For Full T&R	
		Value/unit	**Based on 100 Million Units (in Millions of $)**
Customer Savings (Example)			
	Machine Savings *(Assuming $500k Machine Cost)*	$0.0200	$2.00
	Headcount Savings	$0.0100	$1.00
Total Customer Savings		$0.0300	$3.00
Internal Costs			
	Logistics and Materials	$0.0100	$1.00
	Capital Purchases *(Assuming $500k replacement machine and identical Throughput to Current Tray to Tape and Reel Transfer Machine and 50 machines)*	$0.0500	$5.00
	Additional Headcount for SKU handling (Assuming additional 20 people at $100k/year)	$0.0200	$2.00
Total Internal Costs		$0.0800	$8.00
Internal Benefits			
	Logistics and Materials	$0.0000	$0.00
	Capital Purchases *(Assuming $500k replacement machine and identical Throughput to Current Tray to Tape and Reel Transfer Machine and 50 machines)*	$0.0000	$0.00
	Additional Headcount for SKU handling (Assuming additional 20 people at $100k/year)	$0.0000	$0.00
Total Internal Savings		$0.0000	$0.00

Table 5: Annual cost-benefit analysis

Though this is sample data, it is a representation of how much more of a cost is occurred to Intel over its customers. The machine savings is likely not going to be realized by the customer, because the factories that the companies work in do not run at capacity. Even based on peak volumes that BGA parts are expected to reach, it is not expected that there will be enough benefit gained from customers to offer them tape and reel. The only way that this may make sense is if all customers are willing to receive tape and reel, or if the customers requesting tape and reel do not require receiving parts in trays. Since Intel receives no savings from switching over to tape and reel and the customer benefit is minimal, it does not make sense for Intel to invest in tape and reel.

8.2 Technical and financial hurdles

Based on the cost-benefit analysis, Intel faces very significant technical and financial hurdles, one of the most significant being that Intel must overhaul its IT system in order to support offering tape and reel and trays. The biggest issue for offering tape and reel is how to handle the tension that arises from using a shipping medium that is ideal for smaller quantities versus using a shipping medium that is ideal for large quantities, especially when trays can easily be used for both large and small quantities of processors.

9 Customer ordering behavior

This chapter investigates customer issues that were overlooked when making the request for tape and reel. The current state of how processors are procured throughout the supply chain is evaluated and how likely the model is to change is considered. This evaluation seeks to investigate possible scenarios OEMs could take in order to adjust their inventory policies and how inventory policy changes made by OEMs can potentially improve the tape and reel benefit proposition assuming that Intel does not change the number of SKUs it offers. The current issue with ordering large numbers of processors is that, based on current conditions, processor ordering behavior changes daily in order to adjust for market changes. The investigation seeks to anticipate whether large OEMs are capable of ordering parts in larger quantities. The hypothesis is that, based on current conditions, OEMs do not have the operations capability or financial ability to procure large orders of processors for notebook PCs.

Product life cycles for processors are short, on the order of three to six months. [49] The industry supply chain has about sixteen to twenty four weeks of estimated inventory, and demand forecasting is a major concern. [50] Quanta is one example of a very successful ODM in the Notebook PC business. One of the major challenges that Quanta must address in Quanta's operations is the delivery date, volume and costs for expensive items in notebooks including LCDs, CPUs, and hard disk drives. [51] Managing procurement costs for these items are grounds for competitive advantage, especially procurement of high value parts such as BGA processors.

One of the major issues of why from a customer standpoint it does not make sense to offer tape and reel is because customers will have to forecast demand for two different shipping mediums rather than just one. ODMs are not currently responsible for forecasting demand for processors; this responsibility goes to the OEMs. OEMs, "in order to squeeze margins out of the supply chain, are currently procuring expensive components, such as displays, processors, and batteries from the manufacturers and providing them to the ODMs to

[49] (Sailer, 2010)
[50] (Sailer, 2010)
[51] (Chang, Pan, & Yu, 2008)

integrate."[52] Because the OEMs are responsible for forecasting and managing inventory, ODMs making the requests for their manufacturing lines are not taking into account many different factors including procurement, inventory management, and product life cycle.

9.1 Current state: customer ordering behavior

Based on the current model, ODMs are not currently responsible for purchasing CPUs. For this reason, when ODMs assess the benefits of tape and reel, they are only assessing the benefits that they receive on their SMT lines. Should the model change, and ODMs were also responsible for purchasing CPUs, then they would be better able to make a financial analysis of whether or not tape and reel was a worthwhile financial request. As shown in Figure 12, the ODMs have a very narrow view about the effects of planning for and receiving BGA CPUs in tape and reel.

The ability of OEMs to manage large order quantities is measured by their financial capability, inventory management ability, and based on their current operations.

[52] (Foster, Cheng, Dedrick, & Kraemer, 2006)

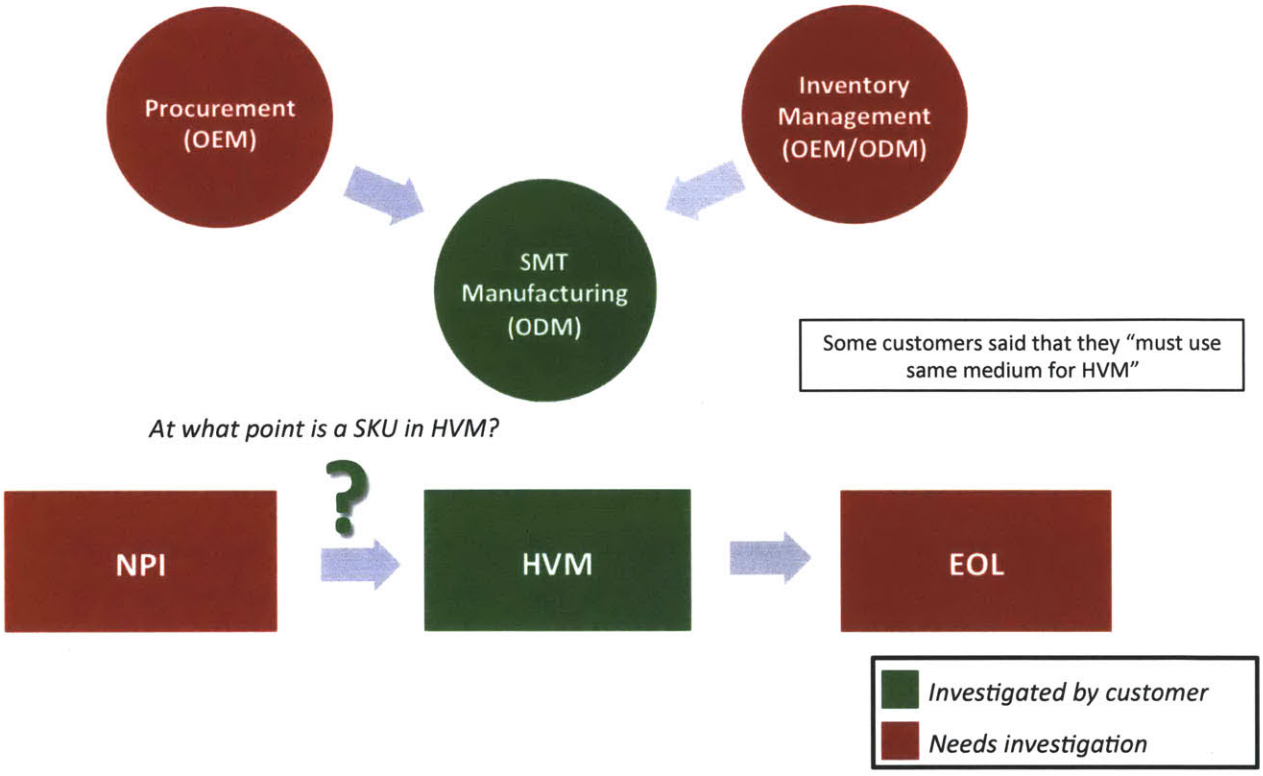

Figure 12: Procurement Issues

Because of the ODM's limited view of the situation, they do not see that even though there will be benefits from a financial standpoint on their manufacturing lines, there will be additional costs for OEMs incurred by receiving BGA CPUs in tape and reel.

9.2 Intel responsiveness to customer

If customers could completely switch over to tape and reel, this could help Intel to justify the cost of offering tape and reel. However, this would be difficult for the customers since "The processor is one of the highest value components in a typical notebook computer and on average has a value approximately double that of the system motherboard. Therefore, not only does the inventory held upstream of final assembly increase, but also this inventory has three times greater value on average than if it did not contain soldered-on processors."[53] Though ODM customers are going to experience some benefits, because they are going to be offered tape and reel, what customers do not realize is that they are now going to have to

[53] (Sailer, 2010)

forecast procurement within their own factories thereby actually increasing the inventory they hold to a certain amount. Even in large ODMs that produce motherboards, some of those customers still have to order small amounts of BGA CPUs for notebooks. They still produce small volumes, and as explained tape and reel is the best fit for a product with fewer SKUs.

Based on the current market conditions, it will be difficult for certain OEMs to be able to order large numbers of CPUs at a time. The major issue is that not all OEMs produce large quantities of notebooks; in fact many OEMs will order a small quantity of processors each day in comparison with other OEMs who order thousands of processors each day. The whole purpose of the VMI hub was so that customers could order quantities whenever they needed them. However, introducing tape and reel introduces a new level of complexity that was not experienced before. Introducing tape and reel will essentially introduce a new product. The typical product life cycle of a processor is approximately three to six months.[54] Given that a processor lifecycle is approximately one year long, each processor goes through a typical life cycle of new product introduction, high volume manufacturing, and end of life. A processor generally is shipped in new product introduction for one month, high volume manufacturing for three months, and end of life for one month. Given these time periods, tape and reel would only be used for two months per SKU, with the needs shifting from SKU to SKU over time, further adding to the inventory management and production planning complexity.

9.3 Fixed order quantity efficiency

If Intel were to be given the option of being able to offer only tape and reel, Intel would benefit from being able to not offer partial quantities to customers. As internal manufacturing complexity grows, it becomes more difficult to manage operations efficiently.[55] One of the major issues that Intel faces is the complexity of not being able to ship all their orders in standard quantities. The added level of complexity of offering their customers increases the level of internal manufacturing complexity and decreases Intel's efficiency, even though Intel is able to offer customers a great deal of flexibility.

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[54] (Sailer, 2010)
[55] (Cecil, Warsing, Barbara, & Flynn, 2009)

10 Recommendations

The following chapter describes ways by which Intel can achieve a win-win situation where both Intel and its customers can benefit from changing the shipping medium within the supply chain at some point in the future. A summary of these options is listed in Table 6.

Primary Issue with Offering Trays and Tape and Reel	Alternative Solution	Pros of the Alternative	Cons of the Alternative
Minimal SMT line savings for major customers	Assist customers to improve tray usage	Low cost for tray loading mechanism beneficial	Will require yearly audit which will require additional headcount
High cost associated with offering BGA CPU in tape and reel	Fan Folded Carrier Tape	Cost efficient; ability to partial; space efficient	Still in the research stage and being tested within Intel
Customer procurement management	Customers may be willing to change ordering behavior	Could result in Intel being able to deliver minimum order quantities and set increments for customers to order	Customers may not yet know how to accurately forecast with this complexity; unable to support small OEMs
Intel SKU Management	Modify planning systems to support two shipping mediums	Will meet customer requirement to support two mediums	Additional headcount; restricted ordering quantities; requires system overhaul

Table 6: Issues and Recommendations

10.1 Alternative Shipping Medium: Fan-folded carrier tape

Fan-folded carrier tape is an opportunity for Intel to potentially benefit to the point of receiving savings. This new shipping medium has the potential to alleviate many of the problems that Intel would experience alleviate many of the problems identified with tape and reel. Tape and reel and fan-folded carrier tape use the same tape design as defined by the EIA standard. The key difference between the two mediums is that for tape and reel, the tape is stored on a reel, and for fan-folded carrier tape the tape is stored in a box. Fan-folded carrier tape is currently in the research stage of investigation at Intel by the Engineering and

Operations group in the Customer Planning and Logistics organization. An example of how fan-folded carrier tape is used is shown in **Error! Reference source not found.**. This picture represents the fan-folded carrier tape that is used for TO-92, a type of transistor. The fan-folded carrier tape for BGA CPUs would look similar to the fan-folded carrier tape shown in Figure 13, except that the design of the carrier tape would match the specifications based on the EIA standard for the specific BGA CPU.

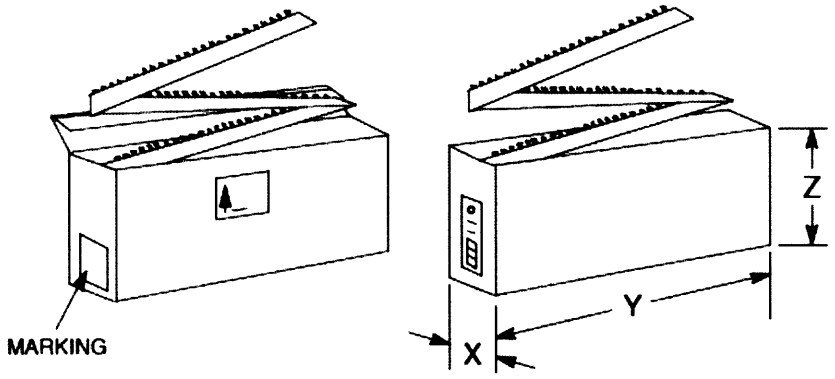

Figure 13: Fan-folded carrier tape specifications

The project is currently being tested on Intel's bare dies. Fan-folded carrier tape has several benefits including space efficiency (no dead space compared to tape and reel), partialling capabilities, and having the same size specifications as tape and reel that is offered today. The implications of integrating fan-folded carrier tape include software changes that have to be made in order to account for folds which will result in uneven spacing between parts on the tape and whether there is space in front of today's pick and place machines to place or hold the boxes, which will no longer be on a reel.

10.2 Helping customers with tray capacity

Another way by which Intel can improve the supply chain is to help customers increase the efficiency by which they process trays. Helping customers increase their tray loader capacity can help customers in the long run without having to change the way processors are shipped. However, implications include maintenance of these machines, who owns these

machines, and how Intel will be fair to different customers. One possibility is perhaps to provide assistance for ODM customers for the purpose of improving the company's lines.

10.3 SKU proliferation

Intel can also explore the possibility of decreasing the number of SKUs it offers. This will make small customers more able to order larger quantities without having to take on the risk of being affected by variable demand. The major issue with why customers are unwilling to order large numbers of processors at a time is due to the large number of SKUs Intel offers. The reason that Intel has not shipped BGA CPUs in tape and reel is specifically because tape and reel is not a good carrier packaging for a product that has so many different SKU offerings. Due to significant variable demand daily, customers are unable to plan appropriately for inventory.

10.4 Supplier interactions that result in shipping medium innovations

There is an option for suppliers to pay an additional price in order to receive BGA CPUs in tape and reel. However, due to the minimal benefit that is received by ODM customers, it is unlikely OEM customers will be willing to pay a higher price in order to receive BGA CPUs in tape and reel. The additional cost that Intel would incur by offering tape and reel would far exceed the price customers would be willing to pay for BGA CPUs.

11 Alternate Scenarios: Key Drivers

There are a number of key drivers that could change the industry landscape, at which point Intel should reconsider the decision to not offer tape and reel. Intel should track some of these key drivers in order to determine if or when is a reasonable point to offer tape and reel in addition to trays. One possible key metric is if all customers were willing to switch over to tape and reel and trays would not have to be offered at all. However, because BGA CPUs are high value in comparison with other components on the motherboard, OEM customers are expected to seek to continue to minimize inventory and opt for trays.

11.1 Intel is the last supplier to ship in tape and reel

If Intel is the last supplier to ship in tape and reel, it is possible that the processor could become the bottleneck for the SMT lines. If all motherboard component suppliers moved to tape and reel as the carrier packaging, the tray pick and place machine would no longer need to be part of the SMT line. The risk of this happening is low, because currently Quad Flat Packs (QFPs) are shipped in trays. Typical QFPs include controllers, programmable microcontrollers, programmable gate arrays, chips with linear applications, and chips with analog integrated circuit applications. The reason they are shipped in trays is in order to protect the pins on these packages. Since they will still be used on motherboards for the foreseeable future, it is unlikely that Intel will be the last supplier to ship motherboard components in trays.

11.2 OEM Ordering Flexibility

If all OEM and ODM customers were willing to switch over to tape and reel and not receive trays at all, all the costs mentioned in this thesis would be decreased significantly. By switching over to tape and reel entirely, most of the costs incurred to support two shipping mediums at once would be removed. In fact, because customers would be ordering in larger quantities, Intel may actually save money because Intel would no longer need to provide customers partialled trays and support extremely small order quantities, decreasing the ordering complexity that occurs within the PC supply chain. However, it is unlikely that the overall switch would happen to tape and reel. Today, both large and small OEM customers order processors in quantities of less than one hundred, not taking into account the quantity of samples ordered. Based on present ordering behavior, it is unlikely that OEM customers, especially small OEM customers, will change their ordering behavior.

11.3 Price changes

There are a number of cost factors that could also impact the tape and reel decision. Among these factors include operator wages and the tray to tape and reel transfer machine. As a business, Intel will not likely make a decision to make a shipping medium change unless Intel can somehow benefit, which could be a possibility if one of these price factors were to change.

However, considering the current economic landscape, it is unlikely that either price factor will change significantly enough for Intel to benefit from offering tape and reel in addition to trays. It is unlikely that operator wages will increase, because ODM factories are being moved further inland in China and to even lower-cost locations like Vietnam to avoid increasing operator costs. Therefore, it is unlikely that operator wages will increase enough to affect the tape and reel decision. In the case of capital equipment purchase, though the costs for implementing tape and reel would decrease as a result, the machine purchase will still result in an expense for Intel and not increase any of the benefits.

12 Conclusion

Based on current conditions, it does not make economic or strategic sense for Intel to offer tape and reel at this time. However, the semiconductor industry moves at a fast and dynamic pace and though each key driver seems unlikely, within a year these conditions could change drastically. For this reason, it is important that the tape and reel decision is monitored, especially since other high mobility product processors are all offered in tape and reel.

Intel will need to closely monitor the industry to have the ability to plan for changes that could happen in the three to five year timeframe. Implementing a change such as tape and reel would take at least a year to fully implement. Due to how long it would take to implement such a major change, it is important that Intel be able to monitor external drivers in order to proactively decide when it would make sense if ever to offer tape and reel, because the change is a large one and would take a long time to implement. Many of the external issues should be monitored over time to see if the potential for risk increases, especially factors considered to be high risk.

Intel is a large organization that is currently undergoing many changes in order to adapt to the changing industry environment. As such, Intel is in the process of investigating many of the different supply chain implications that will need to occur in order to support Intel's strategic vision of driving the PC industry to higher mobility. As an organization, Intel must prioritize which changes are essential for the industry's success.

There are many changes that Intel could make, and Intel must identify which changes are worth investing time and resources in, in order to improve the overall supply chain. In order to prioritize these different changes, Intel must have metrics to assess which changes will reinvigorate the PC supply chain. Tape and reel was assessed in two ways, through a cost-benefit analysis and from a technological standpoint. Based on the analysis provided in this thesis, tape and reel was identified as an initiative that required too much time and resources and did not provide enough benefit to the PC supply chain. Though this was the case, it was valuable to investigate the tape and reel decision, because it ensured that the decision was based on a cost-benefit analysis rather than based solely on organizational barriers to change.

The cost-benefit methodology can be applied to prioritize other changes that the company needs to make in order to improve the supply chain.

The PC industry has hit a critical point where growth is slowing, and Intel is at the forefront of trying to reinvigorate the industry. What this implies for Intel is that as a company, Intel needs to challenge its own processes and do things in new ways that it would not have considered before. Intel must be able to react to the quick changes happening in the industry, and the tape and reel investigation took a closer look at which organizations owned different decisions throughout the supply chain and how processes would be executed. Based on the processes in place, it seems that Intel is well poised to address changes to reinvigorate changes throughout the PC supply chain.

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Appendix A: Customer Interview Questions

Beat rate?

Dedicated Operators for pick and place machines?

Operator cost?

Pick and place machine cost?

Type of pick and place machines used for tray? For tape and reel?

How many trays can be loaded?

Is buying machine add-ons to process trays faster an option? If so, what would the add-ons be?

How many BGA CPU reels could the customer machines handle?

What investments would the customer need to make to switch to T&R?

If we offered both tray and non-partialled T&R, how would they support the equipment in the future?

Would they continue to buy equipment for both?

Appendix B: Sample Data

Volume variables and sample data

Total volume in 2013 = 100M units

Total volume over 5 years = 500M units

Intel variables and sample data

Total cost of Tray to tape and reel transfer machine = $500,000

Number of tray to tape and reel transfer machines = Number of needed tray to tape and reel transfer machines to support assumed peak volume of 100M units = 50 machines

Additional tape and reel material and logistics cost per unit = $0.01

Customer variables and sample data

Sample customer X number of lines in the factory = 100 lines

Additional headcount = 20 people

Annual salary = Annual salary of additional headcount needed to support additional SKUs = $100,000

Maximum pick and place machine operator savings = 8x

Machine beat rate improvement = 1 second/unit

Appendix C: Equations

Section 1: Equations for cost of materials

$$\frac{Additional\ reel\ material\ cost}{Unit} = \frac{(Tape + Cover + Leader + Reel + Band)}{Number\ of\ units/reel}$$

$$\frac{Additional\ shipping\ packaging\ cost}{Unit} = \frac{(Inner\ box + Desiccant + Moisture\ barrier\ bag)}{Number\ of\ units/Reel\ inner\ box} - \frac{(Inner\ box + Desiccant + Moisture\ Barrier\ Bag)}{Number\ of\ units/Tray\ inner\ box} + \frac{Outer\ box + Overpack\ box + Cushion)}{Number\ of\ units/Reel\ outer\ box} - \frac{(Outer\ box + Overpack\ box + Cushion)}{Number\ of\ units/Tray\ outer\ box}$$

$$\frac{Additional\ shipping\ costs}{Unit} = \frac{Shipping\ cost\ of\ a\ reel\ outer\ box}{Number\ of\ units/Reel\ outer\ box} - \frac{Shipping\ cost\ of\ a\ tray\ outer\ box}{Number\ of\ units/Tray\ outer\ box}$$

$$\frac{Additional\ logistics\ and\ materials\ costs}{Unit} = \frac{Additional\ shipping\ costs}{Unit} + \frac{Additional\ shipping\ packaging\ cost}{Unit} + \frac{Additional\ reel\ material\ cost}{Unit}$$

Section 2: Equations for cost of capital expenditure

$$\frac{Capital\ Expenditure}{Unit} = \frac{Number\ of\ tape\ and\ reel\ transfer\ machines * Cost\ of\ the\ tape\ and\ reel\ transfer\ machines}{Total\ volume\ over\ 5\ years}$$

Section 3: Equation for cost of additional SKU handling

$$\frac{Additional\ Headcount\ for\ SKU\ Handling}{Unit} = \frac{Additional\ headcount * Annual\ salary}{Total\ volume\ in\ 2013}$$

Section 4:

Equations for customer machine savings

$$Tray\ Beat\ Rate\left(\frac{Secs}{\frac{board}{line}}\right)$$

$$= \frac{1}{Tray\ Beat\ Rate\left(\frac{\frac{boards}{line}}{day}\right) \Big/ Work\ hours/day \Big/ 60\ min/hr \Big/ 60\ secs/min}$$

$$Tape\ and\ Reel\ Beat\ Rate\left(\frac{secs}{\frac{board}{line}}\right)$$

$$= Tray\ Beat\ Rate\left(\frac{secs}{\frac{board}{line}}\right) - Average\ Time\ Improvement\left(\frac{secs}{\frac{board}{line}}\right)$$

$$Tape\ and\ Reel\ Beat\ Rate\left(\frac{Secs}{\frac{board}{line}}\right)$$

$$= \frac{1}{Tape\ and\ Reel\ Beat\ Rate\left(\frac{\frac{boards}{line}}{day}\right) / Work\ hours/day / 60\ min/hr / 60\ secs/min}$$

N_{Trays}

$= Number\ of\ days\ to\ produce\ 30M\ units\ for\ trays\ (Assuming\ the\ ODM\ has\ 30\%\ of\ production)$

$$= 30M\ units / \frac{Work\ hours}{Day} / Percentage\ of\ lines\ dedicated\ to\ Intel \Big/ Tray\ beat\ rate\left(\frac{\frac{boards}{line}}{hour}\right)$$

$N_{T\&R}$

$= Number\ of\ days\ to\ produce\ 30M\ units\ for\ T\&R\ (Assuming\ the\ ODM\ has\ 30\%\ of\ production)$

$$= 30M\ units / \frac{Work\ hours}{Day} / Percentage\ of\ lines\ dedicated\ to\ Intel \Big/ T\&R\ beat\ rate\left(\frac{\frac{boards}{line}}{hour}\right)$$

$$Number\ of\ lines\ to\ achieve\ full\ efficiency = \frac{(N_{Trays} - N_{T\&R}) * \left(\frac{Work\ hours}{Day}\right)}{T\&R\ beat\ rate\left(\frac{\frac{boards}{line}}{hour}\right)}$$

$$Total\ machine\ costs = (Cost/machine) * (Number\ of\ lines/Factory)$$

$$\frac{Savings}{part} = Total\ machine\ costs/30M\ units$$

Equations for customer headcount savings

$$Operators\ needed\ to\ run\ tray\ machine$$

$$= \frac{\frac{Number\ of\ BGA\ CPUs/tray}{Number\ of\ slots\ dedicated\ to\ BGA\ CPUs}}{Number\ of\ slots\ open * Next\ limiting\ tray\ component}$$

$$Operators\ needed\ to\ run\ tray\ machine = \frac{\frac{Number\ of\ BGA\ CPUs/tray}{Number\ of\ slots\ dedicated\ to\ BGA\ CPUs}}{Number\ of\ slots\ open * Next\ limiting\ tray\ component}$$