# Improving Reuse of Semiconductor Equipment through Benchmarking, Standardization, and Automation

By
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A.B, Biology, Harvard University (1996)

Submitted to the Sloan School of Management
and the Department of Civil and Environmental Engineering
in partial fulfillment of the requirements for the degrees of

**Master of Business Administration**
and
**Master of Science in Civil and Environmental Engineering**

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**Abstract**

The 6D program at Intel® Corporation was set up to improve operations around capital equipment reuse, primarily in their semiconductor manufacturing facilities. The company was faced with a number of challenges, including differing work flows across multiple locations, lack of centralized work flow management, discontinuous inventory information, and other opportunities for cost reduction.

The internship was set up to benchmark and explore potential for integration of best known methods, accumulated both inside and outside the company. Based on interviews, research and quantitative analysis, opportunities were identified for reuse of equipment shipping crates, improvement in warehouse inventory management, and changes in labor models to facilitate better knowledge capture and dissemination.

As a result of this study Intel® Corporation may realize significant improvement in the areas mentioned in terms of cost reduction, process improvement and knowledge management. By using a flexible approach to problem identification and generating organizational interest in the improvements, recommendations were well received and should lead to eventual adoption.

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In memory of my mother, Terry, who, with my father, instilled in me confidence in my abilities and the desire to make life an opportunity for continuous learning. It is all grist for the mill.

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# Chapter 1 Introduction

## *1.1 Summary of Objectives*

As Intel® goes through successive generations of manufacturing technology, and increases wafer size from 200mm to 300mm and beyond, the reuse and sale of used semiconductor process equipment becomes a significant opportunity for cost reduction. In addition, proper handling of decommissioned tools is critical to assure for protection of asset value and compliance with safety protocols.

The 6D program (Decontamination, Decommissioning, Demolition, Demolition of Utilities, Delivery, and Deployment) was formed to standardize and automate the process of moving tools from factory floor to its final destination in reuse, resale, part harvesting, donation or scrap. In less than a year since its formation, there has been a ten-fold reduction in some problem areas. However, to assure "best-in-class" performance in this area, Intel® developed this LFM internship to capture best known methods both inside and outside the company, as well as to make recommendations for improvements based on the benchmarked results.

The internship scope was defined to cover the areas of Decontamination and Delivery, as defined by the 6D Working Group. The bulk of problem identification was spent on the Delivery portion, identifying opportunities to reduce costs and improve performance in tool delivery and storage. Problems were identified through interviews with employees, regular review with program and internship managers, presentations to the 6D Working Group, and feedback from MIT thesis advisors.

Key questions / problems were:

- Can significant cost reductions in capital asset shipping crates be achieved through reuse of crates? This problem involved careful evaluation of the timeline in which the crates are needed, and which subset of tools would achieve the largest Return on Investment (ROI). Crates are tool specific, adding to the challenge.

- What are the best technologies to improve inventory management in capital asset warehouses? Some of the challenges were a rapid increase in storage over the past two years, dependence on legacy database systems, manual processes in inventory verification and in database reconciliation, and complexities of dealing with a 3rd party logistics provider.
- How can Intel® best improve decontamination practices to optimize the process? Challenges are a decentralized reporting structure, dissimilar labor practices and labor structures across sites, loss of expertise in successive tool moves through shifting roles of employees, unavailability of commonly accessible knowledge capture and management, and the challenge of aligning the needs of product manufacturing with 6D processes.

## 1.2 Summary of Research

Initial scope of the project included significant benchmarking, both inside Intel® and in related industries, such as pharmaceutical, chemical and aerospace. The first month was dedicated to a deeper understanding of the 6D process. The intern performed interviews, attended all possible meetings related to the subject, and toured facilities, accumulating information about problems and potential solutions.

The second few months were spent creating pro-forma financial models of proposed solutions, and presenting information to various groups in order to elicit feedback. In addition, the bulk of the work developing tools useful for this analysis was performed during this time.

These tools include, a simulation to evaluate crating availability and need, side-by-side comparisons of equipment tracking technologies, a risk / rework matrix of tool reuse, highlighting critical steps in the process, and a 3-dimensional graphing tool. Microsoft Excel was chosen for most modeling and analysis based on its high portability and availability in the organization. In addition, JMP was used for some statistical analysis where Excel was unwieldy or did not contain the desired functionality.

The final month was spent presenting the proposed solutions to the 6D Working Group and stakeholders, as well as documenting recommendations for handoff to the intern's sponsoring group.

While many of the projects were useful, in terms of value added to the organization, some analysis highlighted the risks of evaluating inaccurate or incomplete data. Several stakeholders indicated significant concern with how the data analysis might be used, suggesting that the 6D program was not yet ready for a full Six-Sigma/Lean approach.

## 1.3 Summary of Recommendations

Proposed solutions offer over $1M/year in avoided cost, as well as significant other un-quantified benefits. Some of these benefits are:

- Proposed creation of a crating reuse decision support tool that would assist stakeholders in various areas of the Delivery process in forecasting, as well as offer the ability to extend crating reuse to tool fixture reuse.
- Additional benefits to automating warehouse tool tracking include reduced risk of lost tools, better availability of information to resale groups, increased speed of locating tools, and improved safety for employees in warehouse environment.
- By highlighting long cycle time between decontamination fault and discovery, demonstrated that investing larger amount of funds in decontamination procedures, including development of additional review, would have significant long-term benefits.
- The benchmarking process helped to identify several best practices which Intel® could utilize to improve 6D, including changing parts of crating material for durability, and shifting the workflow of the decontamination process to being part of production.

## 1.4 Industry Overview

The semiconductor industry began in 1947 with the invention of the transistor at Bell Labs[1]. From this point, it took roughly a decade for the industry to become economically viable. During this period, several companies were founded to compete in the market space, including National

Semiconductor and Fairchild Semiconductor. In addition, companies such as TI, Motorola and GE entered the semiconductor business, and the industry moved to now familiar innovations such as the integrated circuit, silicon based technology, and photo-resist based technologies for mass production.

By 1964, the industry had grown to over $1B in sales. In 1965, Gordon Moore, a soon to be founder of Intel®, predicted exponential growth in semiconductor density by doubling every 24 months. Rapid industry development and prescient predictions such as Moore's set the stage for the founding of Intel® in 1968, AMD in 1969, and Samsung Semiconductor in 1974.

The 80's heralded the development of the personal computer (PC) and continued growth of semiconductor manufacture, surpassing $10B in sales by 1980. Chosen as the central processing unit (CPU) for the IBM PC, Intel® became a familiar benchmark for processing power, as Apple's Macintosh cornered niche markets for desktop computing with Motorola's 68000 series processor. At the same time, U.S. manufacturers were challenged by Japanese attempts to corner the world market for semiconductors. 1986-7 saw significant trade challenges as countries sought to protect and develop domestic manufacturers and expand markets. Semiconductors become integrated in many household products, besides computers.

Through the 1990's, founding of additional computer manufacturers vastly expanded the reach of the PC to millions of people. 1994 saw $100B of sales, and by 2000 sales surpassed $200B. The industry has many players change due to fierce competition. Today Intel®, AMD, Samsung and Toshiba compete to lead the market in various memory technologies, and Intel® and AMD compete to provide processors to PCs around the world.

## 1.5 Company Overview

### 1.5.1 Company History

Intel® was founded in 1968 by Gordon E. Moore and Robert Noyce, both former employees of Fairchild Semiconductor. The company was initially named NM Electronics, after the founders, and was renamed Intel®, or "INTegrated ELectronics" later that year.[2]

1969 saw the introduction of their first memory product, a random access module (RAM) chip, the 3101. Two years later they introduced the first processor, the 4004, and launched their IPO, raising \$6.8M[3]. The 1970's saw Intel® processors installed in equipment such as traffic lights and cash registers. In ten years the company grew to 10,000 employees.

In the early 80's, Intel® further expanded its microprocessor business, and by 1985, exited the RAM market, where it had launched its first product. In 1988 Intel® begins producing flash memory, differentiated from RAM by its ability to store information without the need of a power supply.

By the 1990's, the Pentium® line of products dominated the market for PCs, and made Intel® a household name through the "Intel® Inside" marketing campaign. Processors continued to roughly double in speed, per Moore's prediction, and Intel® focused on developing specialized processing capacity for math, graphics as well as the underlying chipsets to integrate computer systems with peripheral electronics.

### 1.5.2 Intel® Today

As of 2005, Intel® has over 90,000 employees in offices around the world. Revenues were \$34.2B for 2004, and it is ranked 53rd on the Fortune 500 list[4]. The majority of chip manufacturing facilities are located at factories, or "fabs", in the U.S. However, there are also fabs in Israel and Ireland, and facilities in Asia and South America to sort, assemble and test the final product, a circuit with processor, integrated electronics and memory.

Intel® is divided into business units. The Technology Manufacturing Group, or TMG, comprises approximately 80% of employees and other corporate and support organizations comprise the remaining 20%. Within TMG, the some of the main organizations are:

- FSM, or Fab Sort Management - Oversees the fabs as well as the sorting facilities
- A/T, or Assembly Test - Oversees the assembly and testing facilities for final packaging

- TME, or Technology Manufacturing Engineering - Develop technology to assist in the manufacturing process

### 1.5.3 Intel® Culture and Strategy

Intel® culture was strongly shaped by Andrew "Andy" Grove, 4$^{th}$ employee and CEO from 1987 to 1998. As in many organizations, Intel® has developed its own acronyms and methods for doing business. Along with key "values", which are inculcated through facility-wide banners and new employee training, the atmosphere is one of significant competition to achieve agreed-upon deliverables, which are defined all the way from individual to business unit.

Due to the fierce competitiveness of the semiconductor industry, there is a continuous focus not only on individual improvement and pursuit of best known methods, or BKMs, but a combination of risk taking and risk aversion in which new ideas are both heralded and continuously challenged by employees.

In addition, there is a strong focus from the organization towards production, which forms the bulk of revenues. Business groups with Intel® that provide secondary or additive support to manufacturing must prove their demonstrable worth to the bottom line of Intel®'s balance sheet, or to improving the cycle time of production in the fabs.

This focus on the "front end" of production has led to challenges at Intel® to reconcile the fluctuations of the semiconductor industry with the less flexible factors of capital equipment, labor and facilities. While Intel® has moved to a significant portion of non-permanent work force and flexible buildings which may be converted or upgraded for various uses, capturing the embodied value of capital equipment and decreasing capital expenditures on a year-to-year basis is a key factor in Intel®'s future competitive advantage.

# Chapter 2 Project Survey

## *2.1 Brief Description of 6D Process*

The 6D program was initiated in late 2004 by several key employees who saw significant opportunity to reduce costs and improve quality in the used tool handling process. 6D was initiated as the 3D program (Decontamination, Decommissioning and Demolition), and was changed in mid-Spring 2005 to reflect its expanded role encompassing equally important but frequently overlooked stages, Demolition of Utilities, Delivery and Deployment. The stages are described as follows.

**Figure 2-1 - The 6D Process**

"3D" Traditional de-install activities

| Decontamination | Decommission | Demolition | Demo (utilities) | Delivery | Deployment |
|---|---|---|---|---|---|
| Remove and control chemical and physical hazards | Shutdown and isolate | Remove and prep for transport | Remove base-build/ PSSS | Transport, store | Ready for safe, effective deployment in next usage: Re-use, sell, harvest, scrap, donate |

"6D": includes complete cycle to next usage

* Diagram courtesy of 6D Program

### 2.1.1 Decontamination (1D)

Initially it was unclear by the program initiators whether decontamination should come before decommissioning. Further workflow analysis revealed that the two steps were inextricably linked, since equipment could not be effectively shut down without several decontamination steps being performed, such as venting of critical gas lines, and running of high level preventative maintenance routines. Therefore, the first two steps are frequently referred to as "2D" procedures during the development of company-wide guidelines, called VF, or virtual factory, specifications.

Decontamination typically refers to all the procedures that encompass emptying the equipment of hazardous gases, fluids and other chemicals. These run the range of inert gases, such as Nitrogen ($N_2$), to strong acids such as Hydrofluoric Acid (HF) used in etching semiconductor layers, to pyrophorics such as silane[5] ($HSi_4$) used in chemical vapor deposition (CVD) processes.

In addition to emptying the equipment lines of chemicals, equipment using large amounts of acids, called "wet benches", present an additional challenge in that plastic tubing frequently absorbs enough acid during the production process that leaching can occur during long term storage. This means that even careful decontamination may still result in trace levels of low pH fluids accumulating in tubing. In the best-case scenarios, these levels are below the maximum allowable mandated by Intel® safety standards and government regulations governing storage and transport. In a few cases, incomplete decontamination has resulted in higher risk events where re-decontamination procedures must be performed in order to fulfill safety requirements.

### 2.1.2 Decommissioning (2D)

In concert with decontamination, decommissioning refers to shutting down and isolation of equipment from other running equipment in the fab. 6D procedures typically fall into two categories. The first is replacement of a single machine due to upgrade, equipment failure, or differing need in the manufacturing process. The second is large scale demolition of a fab in order to change or upgrade the manufacturing process, such as the change from 200mm to 300mm equipment.

The semiconductor industry has been on a gradual change where wafer size has increased to reflect the greater efficiency in running larger wafers, from 150mm diameter wafers, to 200mm, to 300mm. This efficiency is based on the extremely high fixed costs of building a fab: extensive chemical handling systems, air handling and purification systems, building costs, and labor costs.

While larger diameter equipment typically requires larger sized equipment, the relative efficiency is still significant.

At the end of the 2D processes, the equipment has been deemed sufficiently clean and disconnected from the underlying chemical pump and gas feed systems to be taken apart for movement off the factory floor.

### 2.1.3 Demolition (3D)

With the resolution of 2D processes, equipment may be "demo'ed" for removal from the fab, in preparation for crating, shipping, storage, and deployment or sale. In many cases, equipment such as robotic arms, fragile lenses, equipment with gaps to allow the flow of work in progress (WIP), or other moving parts must be secured. These parts are secured through the use of makeshift tools, or through original equipment manufacturer (OEM) developed tool fixtures, which are specified to safely protect the tool in transit.

The tool must also be protected from moisture and condensation through the addition of desiccants, padded to prevent physical trauma, and wrapped in an airtight seal to assure compliance with OEM specified humidity ranges. During this treatment, a tool is palletized, and once the final equipment preparation is completed, the crate walls are attached in preparation for shipping.

### 2.1.4 Demolition of Utilities (4D)

The utilities and substructure of the tool consist of the pumps, power supply units, and other associated equipment that resides on the level below the factory floor. Much of this equipment requires its own procedures and techniques to properly decontaminate and prepare for shipping or transport. Equipment such as pumps is referred to as non-trivial many (NTM) and may have a separate storage and fulfillment channel from capital assets.

As of December 2005, the end of the internship, the 6D Working Group (6D WG) had only just begun to formalize a process by which these procedures would be codified in VF guidelines. The 6D WG consists of Intel® employees that, based on their interest or association with the tasks involved in 6D, have come to be involved in the standardization of the work process. Consequently, more or less progress may be made in a certain area based on the representation by experienced staff. The development of a formalized proposal for 4D focus coincided with the participation of an Environmental Health and Safety (EHS) engineer who possesses specific interest in developing this area. Work dynamics will be discussed further in Section 2.2.2.

### 2.1.5 Delivery (5D)

The delivery phase encompasses the finalization of packaging to disposition of the tool at its final location, whether it is for reuse in another Intel® fab, resale by the Intel® Resale Corporation (IRC), resale in combination with manufacturing process information, or "technology", by the Special Projects group, disassembly for part harvesting, donation, or scrap. Because the delivery phase can consist of anything from a few weeks to a few years, many opportunities for process improvement existed.

Equipment is subject to a number of stresses that would never be present during normal fab use. For example, shipping may take place via a combination of truck, barge or air transport systems. Storage may be in an Intel® controlled warehouse or in that of a 3rd party logistics (3PL) provider. Equipment may remain on metal racks, or stacked in open space on other equipment. It may remain in the same place for years, or be moved on a regular basis to conform to the needs of the warehouse.

### 2.1.6 Deployment (6D)

The rapid deployment of a reused tool, whether by a customer who has purchased the equipment, or more typically by an Intel® fab which has received the equipment through assignment by a capital asset management team, is truly a critical portion of the process. It is also highly dependant on the preceding phases, which can cause the deployment of a new tool, especially as part of a ramp up of a new technical process, to miss critical deadlines. Because fabs are judged by upper management on the quantity, quality and speed of production, efficient deployment of reused tools is vital in realizing true benefit of a capital asset reuse program.

In addition to delays in the 1D-5D process, which are less common, errors in the process which lead to a damaged or non-functional tool can delay a ramp significantly if the tool is a critical part of the process, or if replacement parts need to be ordered. Therefore, regular successful deployment of a tool should be considered the final determinant in the success of the tool transfer process.

## *2.2 Motivation and Challenges for the Project*

### 2.2.1 Project Motivation and Scope

The 6D program was developed by key employees seeking to standardize processes, automate knowledge management, and rectify costly errors and mistakes in tool transfer. Program members developed a number of working teams to address key areas of concern, such as 2D guidelines, crating specifications, standard operating procedures (SOPs), tool reuse auditing and data management, and a host of other specific concerns such as local coordination with employees that performed the day-to-day work and managed the workflow.

The 6D internship was created out of a desire to evaluate the process holistically, and examine best practices, both inside and outside of Intel®. The majority of employees involved in tool transfer had additional reporting responsibilities. In addition, 6D is a matrixed organization with indirect reporting structure. This added to the challenge of enabling such a holistic perspective, through which large scale rather than local or job specific optimizations could take place. The internship fell under the auspices of the knowledge management (KM) group. The KM group, a subset of TME, had become involved in 6D through internship supervisor Dr. Rahman Khan, who identified significant opportunities knowledge management to resolve knowledge transfer and training problems in the 6D process.

The initial scope of the internship was to cover Decontamination (1D) and Delivery (5D), and involve an investigation of how to improve practices in these two process steps. The specified scope and objectives were to:

- Further Intel®'s knowledge of practices in our industry (wafer fabrication), as well as practices in related/other industries facing similar issues.
- Identify and document best practices among Intel® sites.
- Determine how other organizations develop decontamination procedures, crating standards/specs and handle transportation issues.
- Establish a baseline for improvement: Document the costs, man-hours, cycle-time, and rework of the current decontamination & Delivery processes.

The expected outcomes based on this scope were:

- Comparison of practices across Intel® fabs versus others (various industries, other organizations).
- Recommendation for changes to enable Intel®'s Tool Decontamination and Delivery practices to be world class.
- Transfer the above knowledge to the 6D-KM group.
- Identify and recommend leverage points in the Tool Decontamination and Delivery business process where leading practices should be incorporated to meet Intel®'s present and strategic objectives.
- Prepare research report documenting MIT's thought leadership in hazardous materials handling/transportation, focusing on compliance management and auditing.

The internship began on June 13th, 2005 and concluded on December 9th, running just under 6 months. In this period the expected deliverables changed to some degree as opportunities to apply MIT technical and managerial expertise were identified. The above scope and outcomes, formally defined by a Performance Management Goal Agreement (PMGA) roughly one month after the internship began, did not include direct references to any of the resulting operational analyses performed, or the recommendations that resulted from these analyses. Based on the open-ended definition of the project, there was opportunity to further define the specific deliverables based on benchmarking and further investigation into the process.

### 2.2.2 Project Challenges

The definition of the 6D project that included the final 3 process steps was created as recently as a few months before the internship began, which highlights one of the significant initial challenges in project. There were few, if any documents which effectively defined and documented the steps in the process, the employees involved, the past and current agreed-upon arrangements between fabs and reporting structures, or the most effective methods for achieving process improvement.

In terms of benchmarking, there were few formal channels by which the intern could take advantage of industry relationships to perform the study. While Intel® is a member of industry groups such as SEMI[6] and SEMATECH[7], the employees with the strongest involvement had, by the time of the internship, little involvement in the 6D process. Therefore it was difficult to elicit significant assistance in contacting and building channels of communication. Also, because the 6D program is considered to be part of Intel®'s competitive advantage in the semiconductor industry, there was some concern that benchmarking within the industry might raise awareness significantly of proprietary or confidential business processes and techniques, thus threatening the competitive edge.

6D is a highly matrixed organization, crossing groups such as EHS, KM, FSM, Corporate Services (CS, responsible for tasks such as demolition, crating, etc.), IRC, Finance, and others. There was no specific organization chart to follow in the process of understanding the process or determining appropriate individuals to interview. Instead the work proceeded organically, with leads generating new leads, until the intern achieved a greater understanding of groups' involvement.

As the internship was developed in a fairly open-ended manner, there were many ways to become involved in trivial matters, while missing the more fundamental or significant opportunities to enact positive change in the 6D process. In this regard, early pro-forma evaluation greatly assisted in focusing the scope of research and analysis to determine potential for significant savings and improvements.

Due to the limited amount of time and decentralized organization, there was a challenge to set the stage for recommendations and enact "pull" in the organization for these changes. Regular involvement with key personnel was critical in assuring that the recommendations were well received, and would have the chance to be enacted once the internship was completed.

Finally, given the number of highly talented individuals already involved in process improvements, and the long cycle time of 6D, the challenge remained throughout to look not at today's problems, but at those that might be faced 6 months from now. The recommendations needed to be effective for the period following the internship, or might quickly be obsolete due to the incredibly rapid pace of change. During the internship, a number of changes took place:

- Documents were developed standardizing many processes such as crating
- The 6D WG developed a standard operating procedure (SOP)
- The KM organization greatly extended and developed the tool auditing system to enable tracking of work process from start to finish
- 2D procedures were centralized in on an information technology (IT) infrastructure, to allow for document revision management and access control
- The number of safety incidents was held at zero, down from the previous year's number
- Key managers moved to new positions, and the makeup of the 6D WG changed significantly
- Fab managers signed off on the formal definition of roles and responsibilities to 6D processes within their organizations

These highlights demonstrate this final challenge, of remaining relevant in an organization under pressure to enact rapid change and improvement.

## 2.3 Overview of Program Personnel / Organizational Structure

### 2.3.1 Program Personnel

Based on the combined missions of FSM and CS to standardize the work process involving tool decommissioning and handling, the 6D project is co-managed by one FSM and one CS manager. The 6D WG develops recommendations based on internally developed proposals, or by solicitation from the 6D Managing Oversight Committee (MOC). In turn, the MOC is made up of senior Intel® managers and fab managers, who approve these recommendations.

The 6D WG schedules biweekly meetings, and MOC meetings are scheduled once a month. In addition to WG meetings, several other working teams schedule regular meetings to review workflow additions and changes, as well as discuss potential process improvements.

**Figure 2-2 – 6D Matrix Organizational Structure**

| 6D Working Teams | 6D Management | 6D Oversight |
|---|---|---|
| Tool Transfer Coordinators | **6D Working Group** | **6D MOC** |
| Database Administrators | FSM co-manager<br>CS co-manager | FSM Factory Managers |
| Crating SOP Team | Representatives | Senior Managers |
| 2D Checklist | EHS<br>Warehousing<br>Equipment Resale<br>A/T<br>Finance<br>Knowledge Management | CS<br>EHS<br>Warehousing<br>Resale<br>A/T<br>Finance<br>KM |
| Etc... | | |

In addition to their responsibilities to 6D, many employees involved in the 6D WG have some measure of additional responsibility to other projects within their business unit or group. Thus, the 6D group is not a formal organizational structure, but a matrixed structure with no direct managerial control over participating members, beyond that which is enforced through the seniority of the MOC. Because the 6D WG has some mandate to enable change, it avoids some of the more serious problems of a matrixed structure[8], which is having a task without the ability to execute. However, further empowering WG members would be expected to have a positive effect on the organizational capability.

### 2.3.2 Change Management

Change management is a key challenge for the 6D managers, who are required to not only sell process changes to the members of the WG, but develop traction for those changes to become standardized through the company. A number of avenues are available for this to occur.

- Changes can be codified in VF specifications, which determines a standard operating procedure across Intel® factories
- Leverage from MOC members, typically senior Intel® managers, could bring about top-down pressure in their organizations to effect change
- Participation by member groups in the 6D process can create "pull" within those groups for changes proposed through the WG
- Formal investigations into safety incidents can create negative reinforcement to conforming with older or non-standard workflow

Even with these important avenues for reinforcing standardized processes, by late 2005 there were still a number of groups within Intel® who were either uninvolved or unaware of the 6D program. Because the 6D program's mission, at that point, was to codify procedure in fab capital assets, equipment in the sort and assembly/test manufacturing steps had not yet been engaged. In addition, some smaller and international sites under different corporate structures had not developed leadership interested in standardizing their tool decommissioning programs to 6D SOPs.

One of the critical missions for 6D managers during the period of the internship was to establish single points of contact (POC) at each of the main Intel® manufacturing sites, people who could not only have responsibility for selling the 6D program to site employees, but develop and manage lists of those employees and assure that relevant personnel had received training and information about the 6D matrix organization. The approach of finding and appointing change management "agents" should be considered a critical factor[9] in enabling organizational awareness, as well as a form of coalition building to enable change holistically. Two of the key additional positions assigned at each site were a site employee responsible for coordinating tool transfers and one responsible for maintaining the auditing database of tool moves. In many cases these roles were assigned to the same individual. Regular meetings of all site administrators with 6D WG staff became extremely important in the dissemination of information and development of functional and effective IT systems that accurately mirrored workflow.

### 2.3.3 Organizational Structure and Individual Performance

At Intel®, each employee is tasked with a list of specific deliverables and work areas in which that person is expected to produce measurable results. Because those deliverables are specified down the reporting structure, which follows a traditional organizational design of silos (isolated business units), significant changes in an individual's work load must meet with approval in his or her specific manager and business unit. This may present additional complexity if new or significant deviations in workflow are to be enacted under a matrixed program. Employees may be reluctant to take on additional responsibility for which they will not be evaluated, and which may complicate the fulfillment of primary work requirements.

Other disincentives exist for changes in workflow. Employees must take on some additional responsibility in order to prove that their ideas are valid. They must sell the validity to a number of people before plans might be approved. There is always potential for ideas to be received unfavorably, resulting in diminished status or negative performance review for an employee. There is some evidence that rewarding failure as well as success[10] would be an effective way of creating further incentives for innovation, and that competitive performance reviews may have some disadvantages as well as advantages.

### 2.3.4 Overview of the Knowledge Management Group

The Knowledge Management Group (KM) was formed by a group of key individuals who saw the opportunity for knowledge management to improve processes and efficiency at several levels across Intel®. At its inception, there was a challenge for managers to sell the idea of KM to internal customers, since people often did not understand the concept or its advantages. In addition, competing KM groups added to this challenge.

Today, the KM group is enjoying more business than it can handle, with a number of projects in several business units within Intel®. Most of these programs focus on creating automated tools to handle information, documents, and work process. By addressing inefficiencies in information transfer either within Intel® or with customers or suppliers, the KM group has been able to provide tools with demonstrated ROI and marked improvement in performance.

The benefit of working within the KM group, from an internship perspective, was access to a large pool of potential internal contacts due to recurring business relationships. This greatly helped in examining areas such as RFID, where knowledge was distributed widely throughout the organization.

However, there were challenges as well. Based on research performed during the internship, KM is still not understood by a number of employees, since it does not fall strictly under the auspices of the IT department. KM is an internal consulting department, and by virtue of this, is a cost center. The pressure to demonstrate value, whether in improved work processes, better transfer of knowledge, or proven ROI, can potentially overshadow projects with less tangible results. Finally, because KM exists within the engineering group, TME, as opposed to under a manufacturing group such as FSM, there is a certain outsider status which might be found in other manufacturing organizations. Bridging the gap between engineering and manufacturing, as well as demonstrating value not just to managers but to employees, is a continuous challenge.

## 2.4 Structuring the Research

At the beginning of the internship, there was little indication of how best to proceed in developing a good understanding of the capital asset tool reuse process as it currently stood, and how it compared with other companies in other industries. No survey of the 6D process existed, beyond a few PowerPoint presentations. There was even the question of whether other companies planned to or did reuse tools to the extent proposed by Intel®.

Benchmarking within Intel® was expected to be and was easier than benchmarking at outside companies. Due to the matrixed nature of 6D, there was access to a number of employees in many different organizations. Because the 6D managers at FSM and CS were also sponsors of this internship, they had a number of insights into the process. Finally, due to the placement of the intern within the KM group, the intern's immediate managers had a number of work relationships across Intel® business units through past and current projects.

External benchmarking commenced at the start of the internship, by leveraging the intern's past relationships in the aerospace industry. Transportation of large and sensitive objects was a key aspect of 6D, and of workflow processes at both NASA and Northrop Grumman, where the intern had prior work connections. In addition, by developing a short list of industry leaders in EHS, certain companies could be targeted for investigation.

### 2.4.1 Top-Down Approach / Evaluating Opportunities

There were several possible methods available to benchmark internally. One possible direction would be to closely analyze each step in the 1D and 5D processes to evaluate how each site was performing its function. Another possible direction would be to evaluate how KM and data management affected each of these processes, and how the tasks were being performed at each site. The method chosen was to instead evaluate all steps of the 6D process as they currently stood, holistically, and then evaluate where the best opportunities existed in the 1D and 5D processes, taking into account changes that might occur in all of the steps.

At the end of the first month, there was a much better understanding of how tool reuse worked at Intel®, due to extensive interviews with employees and on-site visits. Through these interviews, a list of key issues was developed that shaped the external benchmarking process, as well as the later research into appropriate operational tools for evaluating change opportunities. These issues will be discussed in Chapter 3.

## 2.4.2 Benchmarking Overview

### 2.4.2.1 Internal Benchmarking

The primary goal of internal benchmarking was to achieve a broad understanding of processes and to develop working relationships with employees at all stages of tool reuse. Based on these relationships, it was assumed that further information could be elicited for pro-forma analysis, and further research into operational improvements. The following list enumerates the successes and opportunities for improvement in the organizational capabilities for internal benchmarking:

**Table 2-1 – Benchmarking Capability within Intel®**

| Business Unit/Group | Success | Opportunities for Improvement |
|---|---|---|
| FSM | Regular access to 6D Manager and a number of other staff members. | Some data access challenging. In some cases, employees could not provide needed and available information. |
| CS | Regular access to 6D Manager and other staff members | Missed out on opportunities to take part in some working team meetings (crating, SOPs), intern unaware of their existence. |
| EHS | Able to contact two individuals involved in 6D. Access to company memberships in industry groups such as SEMI. | Individuals were no longer significantly involved in the 6D program. |
| Warehouse/Shipping | Excellent and early access to key employees. Several facility tours provided good understanding of workflow and challenges. | In some cases, data not available and resources not yet available to improve data management. |
| IRC | Interviewed 6D WG member, as well as IRC president. | Business unit not significantly involved in 6D process. Better understanding of key problems in this group could provide opportunities across 6D. |
| Resale projects / auditing | A few email exchanges. | Lack of significant access to this group limited intern's ability to understand business challenges in terms of 6D. |
| Finance | Good access to key employees and clear understanding of processes. | Limited involvement in 6D program. Increased involvement could be beneficial. |
| KM | Sponsoring group. Extensive access. | |

### 2.4.2.2 External Benchmarking

There were several goals in the external benchmarking study. Because it was unclear how many companies would be engaging in tool reuse to the same degree as Intel®, it was difficult to establish whether the results would be primarily quantitative or qualitative.

## Table 2-2 – Benchmarking Targets and Success Rate

| Company | Unable to contact | Removed, after further evaluation | Contacted, no success in benchmarking | Success in benchmarking |
|---|---|---|---|---|
| Hewlett-Packard | ✓ | | | |
| Pfizer | ✓ | | | |
| DuPont | ✓ | | | |
| Baxter International | | ✓ | | |
| Bristol-Myers Squibb | | ✓ | | |
| Eli Lilly | | ✓ | | |
| BP | | | ✓ | |
| Northrop Grumman | | | ✓ | |
| NASA | | | ✓ | |
| Rohm & Haas | | | ✓ | |
| Boeing | | | ✓ | |
| Johnson & Johnson | | | | ✓ |
| 3M | | | | ✓ |
| Merck | | | | ✓ |

Few if any companies engaged in the same level of tool reuse. Different industries had different business or legal reasons for limiting tool reuse or resale. In the pharmaceutical industry, capital equipment is typically reused for different processes, but liability issues prevent economic resale of used assets. In the chemical industry, size and complexity of installation prevent easy movement of equipment, and differing levels of cost and complexity in factories prevent the necessity of rapid cycle changes in equipment size or type. While aerospace offered some interesting examples of complex apparatus to move expensive equipment, such as airplane parts, in general, large equipment involved in manufacturing did not move from place to place.

While the benchmarking study did result in the acquisition of some internal documents highlighting procedures for storing and moving equipment from participants, the results were primarily qualitative, and served to further direct the analysis of potential operational improvements at Intel®.

### 2.4.3 Tools for Benchmarking

There are a number of tools which can make benchmarking more successful, or at least help narrow the scope of benchmarking to a manageable level. These tools are:

- A clear scope definition which can be articulated, free of company or industry specific jargon[11]
- The Benchmarking Code of Conduct[12]
- Deconstruction of process steps to highlight key aspects, in order to target companies that are best-in-class at those key aspects
- Careful record-keeping of the timeline and path of contacts followed

In order to best describe the goals of external benchmarking companies to individuals who would most likely not be familiar with the 6D program or Intel® procedures, the following description was sent with all initial emails to potential contacts:

This description served several purposes. First, as mentioned, it was a clear definition of scope that would allow employees at other companies to understand the purpose of the study. Second, it was sufficiently broad that it might lead them to participate where a more specific statement of purpose would not. Finally, it was condensed and simple enough that it could be forwarded internally, if the first POC at the company was not the person best suited to be interviewed.

## Figure 2-3 – Text Describing Goals of Benchmarking Study

> *Goals of benchmarking study:*
>
> *Decontamination*
>
> *Establish best practices for developing reliable decontamination procedures, focusing on decommissioning of physical assets with remaining value. The purpose is to assure protection of assets and compliance with environmental regulations.*
>
> *Handling*
>
> *Establish best practices for packing, shipping and storage of expensive and fragile equipment, assuring long-term asset protection, rapid availability and minimum cost.*

The Benchmarking Code of Conduct was the second piece of information sent in initial email exchanges with the target company. This document, produced by the American Productivity & Quality Center, or APQC, highlights the key issues of importance when conducting a benchmarking study and notifies the partner company of the intention to follow a set of ethical guidelines. While this is not a legal document, it does lay out a number of issues critical to a successful exchange.

As benchmarking is a common process across many companies, a number of articles have been published documenting processes that help create the best results. One method[13] is to divide the respective process being examined into steps, each which can be isolated and understood in terms of its core aspect or component. For example, if a hotel chain was looking at best models to set up business centers at their different locations, they might look at Kinko's as an example of a business performing best-in-class catering to mobile business people. This allows the hotel chain to look outside the immediate circle of competitors to a similar business with successful market experience.

Initially, benchmarking can seem like a daunting process, with no clear way of narrowing the vast number of potential collaborators to a manageable list. The companies in this study were isolated through a combination of factors:

- Environmental reputation of company in industry (Good EHS departments probably have better procedures)
- Size of company (larger is better)
- Use of large and expensive equipment
- Access to individuals sympathetic to study (industry / personal contacts)
- Equal weighting across various industries

Finally, one of the most important tools during the benchmarking process and in developing proposals for operational improvements was careful note-taking. The intern kept a daily journal of all individuals mentioned and met, as well as logs of all conversations and a "to do" list of whom to contact and when to contact them. In the first few months of immersion in a new process and company, it is quite easy to be distracted by the constant influx of new information. The first four months of note taking was invaluable when reviewing progress and direction of the internship project. The same challenges of distraction would apply for an employee performing an external benchmarking study. Participants in a benchmarking study are typically pressed for time and taking part in the study out of good will, not necessarily because they expect to receive useful information in return. By careful records-keeping, the bench marker can minimize wasted time and make each new meeting or conversation more productive than the last.

### 2.4.4 A Value Proposition for Survey Participants

While some participants in a benchmarking study might take part out of goodwill, that is, the bench marker or colleagues have a prior business relationship or friendship, or the companies involved have done business together, in general there are few "free lunches", and participants may expect some sort of report of the findings[14]. In addition to their expectations, the bench marker may have more success if he or she can articulate during the introductory period that a report will be forthcoming, and the contents of the report. In addition, participants may be interested in a dialogue of questions.

Inevitably, it is difficult to find the right person to talk to in a company, and in many cases, a contact at the company will pass you to another person, and so on. Some company cultures may be less predisposed to benchmarking. Although there were several contacts available at the aerospace companies surveyed, the majority of the benchmarking was unsuccessful, as individuals were unwilling, unqualified or felt unable for various reasons to take part. Pharmaceutical companies were, on the other hand, quite willing participants.

In general, the most successful exchanges happened where good networking took place. Leveraging connections, especially to senior managers at the target company, was particularly useful in the context of this study.

### 2.4.5 Iterative Benchmarking in a Changing Environment

Benchmarking can be useful for getting a sense of how other industries are handling similar processes or manufacturing steps. However, in a rapidly changing environment, where internal resources are being leveraged to enact significant improvements in processes, iterative benchmarking may offer long-term opportunities for learning. First, by revisiting past companies where exchanges were successful, one can build on positive relationships. Second, the bench marker's understanding of the process will change and the process will change, so different questions may seem relevant in later interviews. This approach may also be more successful than single studies[15], as the expectations for each step in an iterative process will be lower than for a point-in-time study. However, iterative benchmarking may require a multi-year commitment by an employee or group to revisit a project, which can be challenging in a rapidly changing business environment.

## *2.5 Applying Operational Tools*

### 2.5.1 Examining the Operational Process

It is tempting for those with an operations management background to examine the 6D process from a Lean/Six-Sigma perspective. The workflow resembles a complex manufacturing process, with multiple steps, measurable inputs and outputs, quality challenges, and quantifiable rework costs. Currently, there have been no concerted efforts to convert 6D to a "lean" methodology, beyond the approach of standardizing workflow. There are a number of reasons why this would be a significant challenge:

- The process is inherently high-mix, low-volume, with hundreds of equipment types, all requiring different checklists for each of the 6D steps
- The process is still considered a "cost center" by many managers
- Each site possesses its own methods for performing the workflow and some sites are not yet engaged in the standardization process
- Labor models are different at each of the sites, so tasks cannot necessarily be broken down and assigned in a uniform method
- High internal turnover in employees' job descriptions make training and knowledge capture a challenge
- There are significant challenges in measuring quality, as equipment may remain in storage for long periods of time before examined for defects in process (incomplete decontamination, missing parts, damage-in-transit, etc.)
- Data systems are not currently set up to capture cycle time throughout the process
- KM infrastructure for checklists and workflow is not yet complete

With all these challenges, a full Lean/Six-sigma approach might not be possible. However some lean methods can be used to standardize and reduce waste without completely reorganizing the Intel® manufacturing process. It seems unlikely that the 6D program would be preeminent over actual product manufacture, given the importance of production in Intel®'s business operations.

As of December 2005, a number of standardization projects had come to fruition, allowing for mobilization of standardized processes through multiple sites. Through top-down pressure via VF specifications and ratification by fab managers, 2D checklists are slowly being standardized, stored and managed in document repositories, and made available to engineers who do not have expertise in developing their own checklists. Through bottom-up pressure via single points-of-contact at each site, and by participation of coordinators and administrators responsible for tool decommissioning in weekly meetings, knowledge of the 6D program is being disseminated through the company to individuals who are unaware that it exists.

Two documents developed by 6D WG sub-teams have standardized key parts of the workflow in SOPs. First, the 6D SOP has been developed and ratified by the 6D MOC, so a standard set of descriptors of stages and workflow exists. While this does not guarantee that groups will standardize their processes to the SOP, it does provide an agreed-upon guideline which can be used to judge the relative success or failure of sites to conform to Intel® standards.

The second document is a Crating and Packing SOP, which specifies for 3rd party providers of equipment the technical specifications of fasteners, hardware and packing materials which must be used to conform to Intel® requirements. The main purpose of this document was to address the following main issues:

- Damage to equipment due to sub-standard design and materials
- Conformance of tool environment to OEM specified humidity and temperature
- Challenges of meeting size and shape requirements in multi-modal shipping
- Assurance that equipment would be safely stored in 3PL warehouses by specifying maximum height and stacking methods
- Safe transport and loading of equipment based on crate design and tool position (center of gravity)

These two documents, as well as the standardization of 2D specifications, are expected to have an impact in reducing the percentage of issues in successful completion of the 6D process.

As the process is standardized, some aspects of 6D may be conducive to cycle time analysis. The end goal of analysis may not necessarily be a reduction in cycle time, but instead, conformance to guidelines of statistical process control (SPC), which will allow for determination of success or failure of the standardization process. While it is unlikely the accuracy will ever reach 6-Sigma levels, due to the lack of granularity in workflow data capture and site-specificity of processes, this analysis may help isolate and determine problem sites.

Currently, 6D is expected to take a specified number of weeks, an assumption which is used to optimize the relocation of equipment during quarterly equipment planning activities. The optimization is performed by a combination of programmatic and human methods. Lowering the expected timeframe would offer some advantages to allowing increased reuse. However, this could not be at the expense of a successful 6D process execution. There were several concerns raised by 6D WG members that any type of reduction in the timeframe would result in tool damage or incomplete decontamination and would be considered unacceptable risks. This feeling was driven in large part because of the perception that the process was not yet "in control." Underestimating cycle time and jeopardizing ramp, the process of moving a tool or fab from installation to production, would also be a critical and costly mistake. Further cycle time analysis may allow for greater granularity in planning, but only if there are near-zero defects in the process.

Another tool which may allow for significant benefits is workflow analysis through Value Stream Mapping, and other stepwise analysis methods. However, at this time there is most likely not enough standardization in the process across sites to yield significant benefit.

### 2.5.2 Problem Visualization and Root Cause Analysis

Because the bulk of 6D meetings take place as teleconferences – the 6D WG meets quarterly for "face-to-face" meetings and presentations, there are significant challenges in both understanding and communicating the scale of problems. Teleconferences can sometimes devolve into in-depth discussions of unique or isolated problems, where the majority of problems can be subsumed in the presentation of metrics. This is not to say that the 6D WG focused on trivial pursuits, but that it is the natural tendency of people to focus on unique or novel problems while downgrading chronic or long-term problems.

One tool, created as part of the internship around the 2 month mark, was a risk/rework matrix, which allows for easy communication of the relative costs or waste in a system. It is, in a sense, a lean tool which allows for quick understanding of where the major problems exist in a process. Microsoft Visio was used for the creation of this tool, due to its commonality in the organization and ease of creating graphical flowcharts. See Appendix B.

On the X-axis, the steps proceed in order, as defined by the 6D SOP. Along the bottom the approximate cycle time of each step is listed. On the Y-axis, increasing in order of relative severity are the costs / risk associated with failure. Arcs associate the initiating step for a failure, cost or risk with the resulting problem. In addition, some percentage error or probability can be associated with the resulting state.

In this manner, it is possible to identify and communicate high error steps in the process, and where those problems are discovered. Particularly long cycles between failure creation and discovery present particularly complex challenges for long-term reduction of error rate. Specifically, in the 6D scenario, changing employee roles make root cause analysis more and more difficult, the longer the time period before the problem is discovered. The other challenge with long cycles is that it is difficult to measure the success of a new procedure or proposed solution. With shorter cycle failure/discovery rates, it is reasonable to assume that root cause analysis by investigative team or research analysis might be fairly successful.

With long cycle time events, some research indicates that focus on process metrics[16] rather than result metrics are a more effective way for driving success. That is, instead of measuring the number of successful tool transfers, measuring the number of times a tool was transferred within a specified time would be more useful. The challenge of this logic is in convincing results-oriented team members of the efficacy procedures such as cycle time metrics. A combination of process / design improvements and process metrics would likely be the most effective way to control the 6D process.

### 2.5.3 Financial Analysis

Pro-forma financial models are a useful tool to quickly screen an idea or group of ideas for viability. In the case of the 6D program, little actual quantification of the cost of various processes had been performed. Though the cost of tools damaged by incorrect or incomplete handling was an initial driver in the founding of the 6D program, and the benefits of tool reuse were well understood, the hidden costs of tool reuse had not been evaluated. Traditional measures of numbers of employees or equipment purchased would have been overwhelming to accumulate. As mentioned in Section 2.2.2, employees frequently held additional responsibilities beyond 6D work. Therefore, the method chosen to identify relative costs of tool transfer was to estimate labor time and approximate scale of other expenditures.

Based on the first month's research in conversations, interviews and site tours, the intern had several hypotheses about where potential sources of hidden cost could be discovered, and potentially eliminated:

- Cost of custom crating for each tool transferred or stored
    - Could crates be reused for similar tool types?
    - Could crates be standardized to a certain size, and reused?
- Cost of inventory maintenance, tool location, and delays
    - Could an automated tracking system, such as RFID, speed inventory counts?
    - Could automation systems allow for more rapid location of equipment in the warehouse?
    - Could better integration between company databases decrease administrative costs and increase accuracy?
- Cost of tools damaged / destroyed by incomplete decontamination, and associated rework
    - Are labor models correct to optimally address this chronic problem?
    - Is the best method for improvement continuous, or "brute force"?

These costs seemed especially apparent in the Delivery (5D) step, which had a number of high associated costs due to the physical nature of moving and storing large pieces of capital equipment. To begin to understand the relative size of these costs, the following information was acquired:

**Table 2-3 – Relevant Data and Acquisition Method**

| Data | Acquisition Method |
|---|---|
| Cost of Labor | Finance dept. estimated cost for full time employee, $/hour |
| Cost of Capital | Finance dept. |
| Cost of Crating | CS, 6D Manager estimates |
| Average Storage Time | Initial estimates by warehouse manager; more accurate estimates were developed by analyzing data from warehouse inventory system |
| Annual Tool Transfer | 6D program estimates, planning projections |
| Cost of "Lost" Tools | Replacement value of tools damaged due to process failure |
| Cost of Decon. Rework | Labor expense in decontamination rework, EHS engineer |
| Labor time for inventory | Interviews with warehouse manager |
| Cost of warehouse space | Interviews with warehouse manager |
| Cost of RFID equipment | Market research |
| Admin cost of crate reuse program | Currently in progress by Intel® employee |

Using this data and a 6 year "horizon"[17], it was possible to determine the potential savings of a crating reuse program, the relative expense of the current warehouse inventory system and relative benefit of automation, and the expected cost of improper decontamination work. Prior to this pro-forma analysis, the information had not been accumulated in one place. Completed two months after the start of the internship, it became fundamental in both defining the remainder of the internship, as well as instrumental in demonstrating the potential value of further analysis of the relative situations.

While this analysis was by no means perfectly accurate or completely reflected all the costs in the system, it did allow for highlighting areas which had not yet been examined by the 6D WG, and which offered significant benefit for further cost reduction, as increasing progress was made on standardization of other steps.

### 2.5.4 Integration of Automation Technologies

While pro-forma analysis served as an early decision support tool for shaping the direction of the internship, other automation technologies seemed promising for supporting smoother management of the Delivery (5D) process. Two issues were of key importance: determining whether a crating reuse program could be successful, and evaluating the relative benefit of investing in inventory management systems.

#### 2.5.4.1 Crating Decision Support Tool

Equipment crates, especially those conforming to the new Crating SOP, are particularly expensive to manufacture in the U.S. Typically a tool requires some number of crates (a crate set), based on the size of the tool and its technology level, 150mm, 200mm, or 300mm. Newer technology tools typically require more crates. Some crate sets, using wood specified for international shipping, can cost over $100K. While crates do undergo some stress and damage in shipping, the crates are typically built to support several multiples of the weight of the tool, and discarding the crate set after one use seemed wasteful.

Initial estimates of crating reuse showed that based on average interment in the warehouse system, a crating reuse program could not only be useful but cut costs by 50% over 6 years. However, these estimates were based on a large assumption, which was that all crates were essentially the same, and was not the case. Each tool requires a specific crate, and there are over a hundred tool types supported in the typical Intel® fab. This complexity meant that an accurate estimate of savings would have to account for overlapping deadlines when a crate would be needed (a tool exited the fab) or available (tool installed in new location), as well as a panoply of crate types, and the relative cost of crates.

There are several methods initially to evaluate a crating reuse program without resorting to more advanced analysis. These are as follows:

1. Keep all the crates for reuse
2. Keep the most expensive crates of a subset of the tools (for example, the most expensive top 25/50/75 by tool type)

3. Keep the crates with the shortest interment in the warehouse or cycle time in the system
4. Keep the crates from the largest number of tools in inventory (for example, the most numerous tools by tool type, by top 25/50/75)

The first option seems particularly problematic, especially if the cost of storing the crates is unclear, it is unknown whether the crates will be used or how long they will remain in storage. In addition, to perform a proof-of-concept, some selection subset must be made. Options 2 through 4 all present the same question, whether the timeline of need and availability matches the criteria of choice. This question can only be resolved through analysis. For a discussion of results, please see Section 3.3.1.

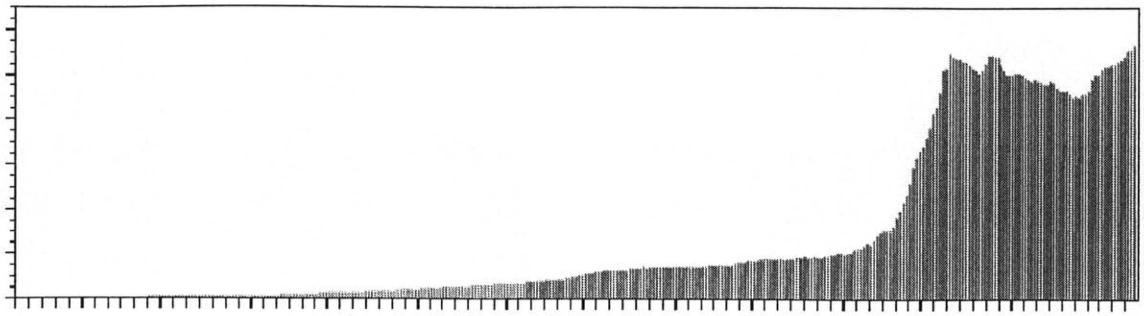
Because planning of tool reuse and purchase is performed on a quarterly basis, projections are available in decreasing levels of accuracy for several years in the future. In addition, historical data is available. While some tools go from "dock to dock" for reuse, others remain in the warehouse for some period of time. The combination of historical and projection analysis can provide a more compelling case to senior managers on whether to progress on a significant undertaking.

Initially, analysis was performed on historical data, as it was easier to obtain, and had been required for the pro-forma analysis. Later, projection analysis was performed. One should not understate the challenges of this analysis. While Intel® is a particularly easy place to obtain information, new questions can often require new data formats. Much of the data had to be reformatted to support this scale of data analysis. Section 2.5.5 will discuss this in more detail.

#### 2.5.4.2 Auto-tracking Technologies

A number of significant challenges in inventory management became evident after an initial month of investigation. Namely, due to enormous increases in inventory size, the legacy systems of managing capital assets were inadequate for accurate and rapid verification and management of warehouse counts.

**Figure 2-4 – Weekly Warehouse Inventory # of Crates (1999-Present)**



One way in which increased inventory had unmanageably scaled workload was in inventory cycle counts. In the majority of warehouses, 10% cycle counts are performed monthly to verify inventory numbers. These are performed by a two step process, randomly extracting 10% of asset counts from the warehouse database and locating them in the warehouse, and randomly counting 10% of assets on the warehouse floor and locating them in the database. This cycle count is supplemented by biannual 100% inventory counts. This system is completely manual and requires a significant commitment of labor to assure accuracy.

Because the warehouse system is a cost center, upper management may be reluctant to invest additional labor resources for these tasks. Sourcing additional labor has not yet been possible for managers given the relative rapidity with which inventory has increased, the relative newness of this problem, and limitations in sourcing new staff.

Added to the challenge of inventory management is the only recent introduction of a uniform asset labeling system. This was brought about due to the ramp-up of 6D auditing databases, which introduced standardized labels and barcodes to the sides of all assets entering storage. Still, there has not been a retroactive project to label all old assets, so inventory audits have been punctuated with discovery of unrecorded tools, as well as hunts for tools that are listed in databases and, for often unexplained reasons, no longer in storage.

Missing assets can be frustrating for employees, especially those tasked with reselling used assets such as IRC. These "missing" tools have only occurred in a handful of cases, but have been the source of numerous discussions. It is unclear whether these problems have come about due to employee error, insufficiency of the monthly cycle counts to accurately measure inventory, by lack of proper access control to inventory (non-warehouse employees may sometimes access equipment without notifying warehouse staff), or by some other incidental loss.

The warehouse system, with a large number of assets that change building locations infrequently, is a high potential opportunity for a more automated tracking system which reduces inventory time and increases accuracy and availability of inventory information. Several potential solutions presented themselves at the outset. First, because bar-coding of assets is already in progress, a handheld scanning system allowing for more rapid data capture seemed like it would have a good potential return on investment (ROI). Second, a RFID[18] (Radio Frequency IDentification) solution offering inventory verification at even higher speeds with even lower labor input appeared to hold additional potential. While the initial financial model indicated that the implementation cost of RFID would be roughly equal to the current labor expense, there may be additional benefits to automated tracking which should be evaluated in addition to avoided cost. Third, strategic investments by Intel® in RFID startups, as well as pilot projects at Intel® to leverage RFID raised the potential for a successful proof-of-concept that would help demonstrate the viability of this technology. Section 3.3.2 discusses the results of a survey of potential solutions, as well as current industry trends in successful RFID solutions.

#### 2.5.4.3 Database Integration

A second challenge to the problem of inventory management is that of legacy systems and the lack of integration between company points-of-record and warehouse systems. Currently, Intel® manages records on an SAP system, which serves as its point of record for asset holdings. During the introduction of SAP several years, ago, Intel® decided not to integrate warehouse inventory systems into the rollout. Consequently, the warehouse database has been running on legacy software which is now considered end-of-life, due to lack of maintainability by IT staff.

Adding to the complexity of the data management challenge is a third database system, maintained by Intel®'s 3PL warehouse provider, where the majority of capital assets are stored. This system, itemizing current inventory as well as floor location, is typically handed off to Intel® in the form of a Microsoft Excel spreadsheet.

Warehouse staff is expected to reconcile data between SAP, the warehouse database, the 3PL system and actual physical inventory in a fully manual process. Even the most able employee could be expected to make mistakes under this sort of system. In addition to errors, the expense of performing data management manually adds several layers of wasted time and rework which could be a good opportunity for an automated solution. However, as mentioned before, it is extremely challenging to have allocations approved for such projects, due to the lack of revenue generation.

### 2.5.5 Data Availability and Integrity

Availability of data can vary a good deal from company to company. At Intel®, focus on systems automation and data capture has resulted in a good deal of information available for analysis. However, frequently analysis reveals questions that the data is unstructured or unsuited to answer. This may take one of several forms:

- Data may simply not be available for the period of time or scope for which the analysis is desired
- It may be difficult to obtain data or additional training may be required to access databases
- Data may not be segmented exactly as needed, requiring extrapolation
- Data may be inaccurate or regularly changing, challenging the validity of analysis
- Data may be inaccurately presented or calculated because it has never been examined
- There may not be a large enough subset of data for conclusive analysis

In all of the analyses discussed in Chapter 3, one or several of the challenges presented itself. In general, Intel® is a fairly easy place to obtain access to data. However, it is frequently "raw" and requires significant processing to yield good results. This requires familiarity not only with the data, but with the capabilities of software to perform standardization of data.

While Microsoft Excel was chosen based on its ubiquity within the company, a number of shortcomings presented themselves during analysis. These were:

- Weak text and pattern matching capabilities, which limited the ease of moving from text to numerical representation
- Moderate abilities to sort and group data, especially in tools such as Pivot tables
- Slow integration with database systems, especially OLAP "cubes", resulting in difficulty in pulling in current data for analysis

On the positive side, Excel offers fairly straightforward tools for large-scale evaluation of numerical functions, allowing for extremely rapid prototyping of decision support systems. Functions such as SUMPRODUCT and VLOOKUP greatly reduced the necessity to look into a programmatic solution, which should allow for non-programmers to access the potential of data analysis.

One of the significant challenges observed in data analysis is the resistance one encounters when presenting results which may threaten the status quo. Even when the analysis is meant for informational purposes rather than judging performance of different groups, individuals may be concerned with the impact that data has on their activities.

This issue came about during the internship, based on the request of a 6D manager to evaluate 6D cycle time using CS schedule data. While it was difficult to draw statistical conclusions based on the low frequency of occurrences of specific tool decontaminations, some members of the 6D WG were strenuously concerned that the analysis might be used to prematurely decrease cycle time before the process was "in control". In this sense, managerial tools such as stakeholder analysis, discussed in Section 2.6.1, may be appropriate to understand the audience before important presentations. Based on the intern's experience, critical feedback may come from unexpected persons, and hinder the success of a data-intensive presentation. It is also worth investigating what assumptions might be challenged after an analysis by discussing this issue with project allies, before a public presentation of results.

### 2.5.6 Knowledge Capture and Management

Though specific methods of knowledge capture and management were not addressed in depth during the internship, because the project was under the auspices of the KM group, there are several methods that were observed as highly effective leveraging tacit knowledge infrastructure.

The 6D program presented a major challenge to encompass a previously decentralized process into a centralized and matrixed organization with standardized workflow. One of the projects that effectively managed data management and at the same time helped define the workflow was the reuse auditing application. By defining its mission early on to accurately capture the actual workflow of the project, in effect, it helped define and standardize operating procedures through regular revisions and stakeholder meetings. Data management software, whether off-the-shelf or custom developed, should be seen as having a strong effect in defining the procedures of a company, even if this effect is not intentional.

Another important tool in knowledge management is centralization of knowledge into a standardized and easily accessible platform for publishing and retrieval. This can be in the form of a document management system, shared web site, or "wiki"[19] type interface. Typically at a large company, data is dispersed and communicated through commonly inaccessible streams such as email and local file storage. If a group is working on an important document, determining the latest version and revisions made could be a very difficult task. Centralizing captured knowledge has the effect of making it live, more likely to be accessed and changed by interested parties. The greatest threat to the value of knowledge is to have it inaccessible when needed. This was evidenced on several occasions when the intern was able to provide critical information to parties who *should* have had access to the information, but were unaware of how to access it.

The issue of knowledge accessibility comes up especially in relation to tacit knowledge; that held by employees but not recorded in any particular form. The majority of the most useful information obtained during the first month of interviews was of this form. Not only had these insights been unavailable prior to the interviews, but were unlikely to be revealed by the most common mode of communication in the 6D group, weekly conference calls. Rapid knowledge transfer might be an effective methodology to close the gaps between tacit and captured knowledge in a way that assures knowledge capture and utilization[20].

To this degree, a disinterested outside observer, such as an intern, can often capture a great deal of information about the real problems faced by a company, due to his or her lack of involvement in the politics of the workplace. One-on-one interviews led to several common threads of problems that might never have been revealed, even though several individuals were aware of them.

Knowledge loss is the counterpoint to knowledge capture and management, and a significant problem at Intel® due to rapidly changing employee roles. As engineers change from one job to another, the embodied experience in procedures such as decontamination can vanish, taking with him or her very high value knowledge. To recreate that knowledge in a new group of employees is often expensive both in labor time and in errors and rework. This lesson was revisited again and again in viewing the challenges of 6D.

### 2.5.7 Training and Knowledge Dissemination

Training and knowledge capture are critically linked. Whether a company communicates primarily through live meetings, teleconferences, presentations, email or other forms, understanding the connection between knowledge capture and knowledge dissemination is as critical as performing either of those steps alone. A knowledge management program is useless if that knowledge is not funneled to those who need it, in an easily understandable form. Training is ineffective if it does not draw in the most recent and effective methods.

This can be a particular challenge if the knowledge generation and dissemination loops are separated by distance or time. In the example of decontamination, engineers who develop BKM's on a set of equipment may be in completely different jobs by the time a new employee must understand and perform a similar task. This may be especially acute if procedures are rapidly changing, in the case of new and different equipment, or if methods are rapidly improving.

While Intel® has a set of methods for duplicating procedures in the production process, called "Copy Exactly", this method is less useful when differing labor models, non-quantitative processes, or when variations in the workflow exist across sites or fabs. In the case of 2D, variations from site-to-site in exact layout of equipment and connections require a set of procedures that are unique between factories. Additional standardization may occur to make 2D similar across sites, especially with new focus on VF specifications for procedures, but the focus on production rather than decommissioning of equipment will most likely allow differences to occur between sites.

The common opinion among engineers involved in decontamination was that any procedural document had to be met with regular peer review, even if those procedures had been vetted in prior 6D events. The high risk associated with failure to properly decontaminate tools before removal means that any variation in the installation had to be met with vigilance and caution. It is likely that procedure development in the 2D phase will remain rooted in review by domain experts, rather than automated through extensive definition and documentation. Consequently, training programs should take into account that knowledge will often remain in the hands of the experts, and the most effective knowledge transfer will frequently occur between employees[21], rather than mediated by a KM infrastructure.

Finally, because training plays a key role in assuring that both tacit and explicit knowledge are disseminated to relevant stakeholders, an appropriate structure must be determined for training programs that assures staff are prepared both to use the knowledge, as well as use insights in circumstances when available knowledge is not sufficient. Training regimens such as "learning by doing" and simulations may be the most appropriate methods[22] for assuring compliance and understanding in 6D processes.

### 2.5.8 Elimination of Risk / Legal Challenges

The risk/rework matrix, as discussed in Section 2.5.2, shows how visualization can help identify major risks and cost in a process. However, while elimination of costs such as crating and reduction in labor for inventory counts may be evaluated using strict financial measures, risk that may result in human injury must be evaluated on a completely different set of criteria.

A number of recent legal rulings and resulting studies have shown that companies who identify potential improvements that reduce risk to consumers and do not undertake action may frequently be met by unfavorable jury rulings[23]. Initial research is inconclusive about whether this extends to employees and manufacturing processes, but analysis of workflows where injury is a risk should take into account the potential hazard encountered by even quantifying those risks.

At Intel®, company doctrine is to dedicate whatever resources necessary to assure that employees are safe in all work performed. This even extends to risks employees may face outside of the workplace, as frequent banners in dining halls and corridors exhort staff to drive safely and use handrails on stairs. Though these signs can seem unusual to the outsider, there is an obvious benefit to engaging employees in a holistic approach to safety. The cost of workman's compensation and health insurance are significant for companies, and reducing injuries on and off the job is by no means altruistic.

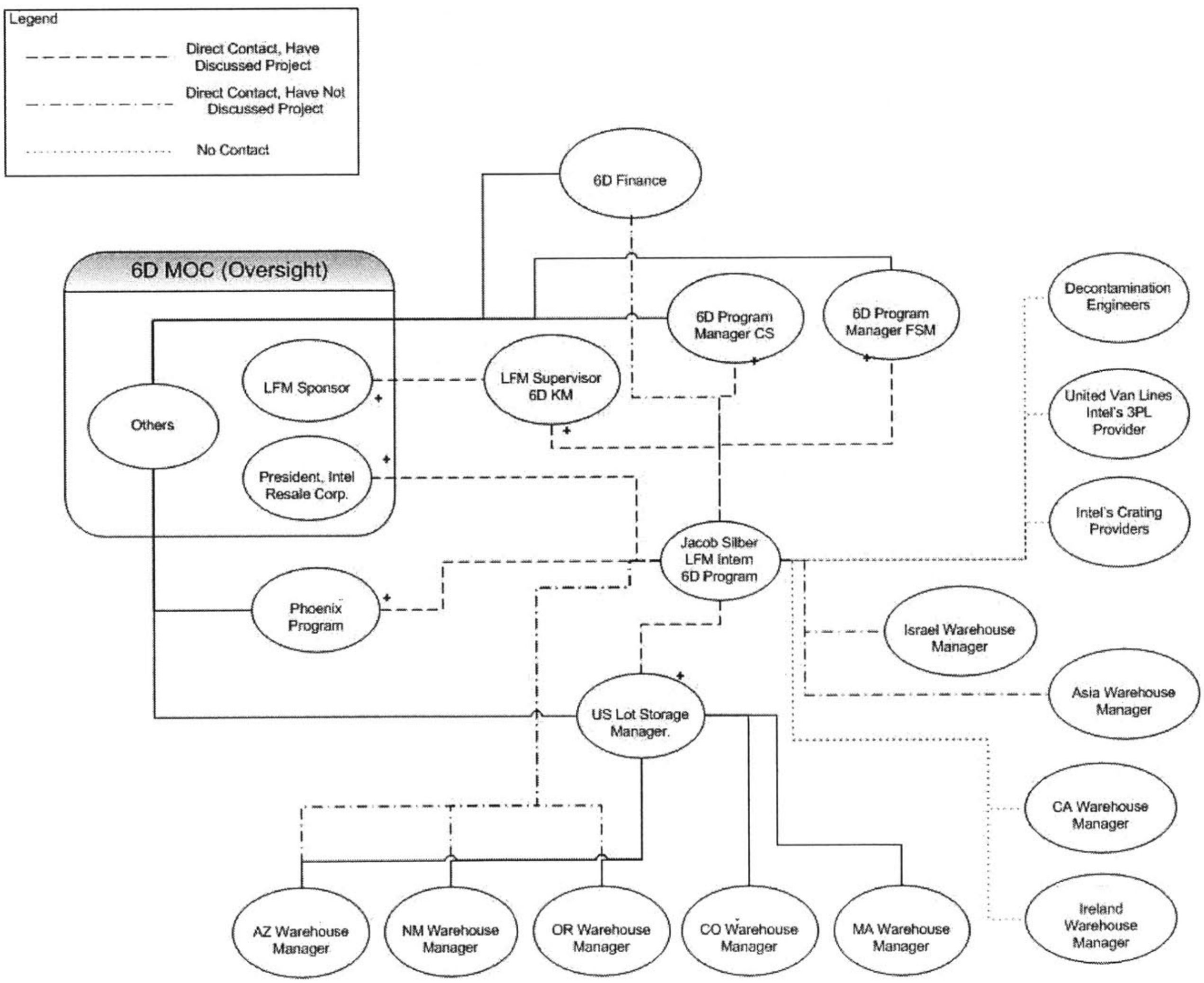
In evaluating potential costs and risks, the intern took the approach of indicating which should be reduced at a financial benefit (costs) and which must be reduced in order to improve safety (employee risks). While better training and knowledge capture might decrease cost of damaged equipment, it is the reduction in risk to employees which is often cited as the real benefit. In general, it appears that benefits are difficult to quantify.

## *2.6 Implementation Frameworks for Project Success*

### 2.6.1 Stakeholder Analysis

A useful tool for visualizing and informally measuring support for a project is stakeholder analysis. This flowchart tool displays relationships between the project initiator and involved parties. It may include team members, other organizations, or anyone that may have an impact on the progress of the project.

**Figure 2-5 - Stakeholder Analysis for RFID Project**




Stakeholder analysis was performed for several projects during the period of the internship (Figure 2-5). This may be especially useful prior to presentations as a way to evaluate potential resistance to the recommendations being made, and consequently clarify and focus the presentation to assure that those concerns are addressed. If the concerns cannot be addressed, at least it will be preparation for any resistance met. These documents are malleable and can change to reflect shifting support, with +'s and –'s indicating support or resistance to a given project.

### 2.6.2 Building Project Support

While stakeholder analysis is a way to focus the thought process about support for a project, in general, a presentation is not a good place to sway the opinion of dissenters. People frequently react negatively to new information, especially in a highly competitive environment where there is the potential to win political capital through such dissent.

During an internship presentation of 6D cycle time information, several concerns by the audience had to be addressed in a confrontational manner. While the data accuracy was not in debate, the use of it was. Proper evaluation of the implications of the data had not been performed.

In the case of crating and RFID, numerous conversations with stakeholders on a one-on-one basis had preceded any formal presentations. Consequently, during larger presentations of the information, supporters could voice their accord for the conclusions if dissenting opinions were raised. In addition, a long term, individual approach to consensus building was successful in assuring that the project had momentum after the internship completed.

Regular communication with stakeholders, addressing their concerns and assisting in tangential projects all helped a great deal in assuring that the internship goals were successfully met.

### 2.6.3 Scope Definition Through Interviewing

Because the specifics of the deliverables were relatively undefined at the beginning of the internship, much of the definition came about through the interview process that occurred during the first month. By establishing contacts through networking within Intel® and the 6D group, the intern determined a list of individuals with whom to set up conversations and investigate their involvement in tool transfer.

This process was important in discovering a number of the potential problem areas that were later addressed through analysis. Repetitive problem identification is a good sign that several individuals have concerns with a specific aspect of the process. On the other hand, one must be careful to sort out whether the problems lie in operational issues, political motivations or differences between organizational groups. At Intel®, each fab not only has its own personnel structure, but can have different methods of dealing with the same problem. At the same time, regional differences can reflect in work practices and work interactions. As companies expand global operations, it will be critical for managers to understand how these differences affect collaboration between sites.

Lack of access to parts of organizations had a significant effect on the internship in terms of limiting the capability to understand problems in the 2D process. This might speak to a lack of leadership in the area, the isolation between different work units resulting in unawareness of common goal, or resistance to change. Regardless, lack of access might cause a loss of significant opportunities for investigation and process improvement.

Careful preparation for interviews is also important[24] so that they are valuable for both parties. Typically interest in participating in a new study wanes with repeated requests for time, unless the participant feels that the results are valuable. In addition, interviews can be structured, unstructured or anywhere in between. Questions that help to shape the path of an interview may also steer the conversation away from key opportunities. A combination of well developed questions and free-form conversation is important for good results.

## 2.7 Strategic Objectives

With the number of skilled employees working on the 6D program, it was a challenge to shape the research and analysis so that the results would be useful when the internship was complete. This was especially true given the rapidity of change in 6D just over the short period of time of six months. Aligning a comprehensive research project with the long term strategic objectives of the 6D program was a unique challenge.

A number of problems, even those specified in the internship description, were already being addressed by the time the internship started. In other areas, domain expertise outstripped any contributions that could be made by an individual working outside that domain. Two methods of project choice helped shape the research direction. First, by examining parts of the process in which little attention has been directed, opportunities may come about for holistic solutions which have significant impacts. A comparative example would be looking at double-sided printing at an office printer. The amount of paper saved by converting one printer to print double-sided by default is small, but across an organization, over many printers, the savings might be significant.

Second, by taking note of processes that employees identify as wasteful, additional opportunities may come about. The waste may be in repetitive inventory processes that can be automated, lost assets such as crates that can be reused, or knowledge lost through lack of effective KM practices. This emphasizes the importance of the interview process and demonstrates that many of the best ideas will come from those who are working the process on a day-to-day basis.

Finally, strategic planning of research requires some measure of prognostication in terms of when problems will be solved. If the expectation is that problems will not be solved, regardless of the allocation of resources, the best course of action may be to devote research and analysis to reasons why. Otherwise, accounting for the panoply of projects that already exist, where will the company be in 6 months? What challenges will it face? A thorough historical and current understanding of the process is critical in making predictions of a strategic nature, especially in a rapidly changing environment such as Intel®.

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# Chapter 3 Research Findings

## 3.1 Overview of Findings

Major analysis performed in the areas of crating reuse, warehouse inventory management and decontamination yielded significant results as to methods for reduction in costs and improvements in quality and availability of assets and information. Final presentation of the results met with positive feedback from 6D managers and 6D WG members, both in terms of the methodology as well as the recommendations. Chapter 3 will involve a discussion of those findings, as well as a technical discussion of the analysis involved.

## 3.2 Presentation of Benchmarking Findings

Benchmarking results were primarily qualitative due to the variance between industries in process and equipment type. The intern noted several best practices occurring at other companies which could be useful for Intel®.

In terms of crating and movement of equipment, examination of more durable materials could lead to more reusable crates. In some cases, crates are constructed out of aluminum[25]. In the aerospace industry, packaging (called tools) is often custom made as parts being transferred are unique to the company. However, despite the low numbers of parts being transferred, the tools are standardized for a given part type. Reuse of this equipment occurs despite the low volume of parts being transported, mostly because of the high expense of constructing a tool[26]. Use of more durable materials for crate pallets could be especially important, as the pallets bear the brunt of the load of heavy semiconductor equipment.

Several companies[27] had looked into automated tracking and sensing technologies, such as bar-coding and shock detectors. In the case of bar-coding, the company owned its own warehouses and so could dictate the layout of equipment storage. This is in comparison to Intel®, where the majority of equipment is stored by 3PL providers. Changes in 3PL contracts to facilitate inventory management could not only speed the process of cycle counts but also improve accuracy and safety.

The majority of companies interviewed do not resell equipment. In the pharmaceutical industry, liability issues are too great for a ROI on resale[28]. In the chemical industry, much of the equipment is large and difficult to move. Plants are often decommissioned for scrap rather than resale as the equipment typically remains in place for decades. Because pharmaceutical companies typically run different production processes on the same equipment, extensive decontamination procedures are in place to assure that there is no cross contamination. Regulation by government agencies further drives this process. Typically decontamination is seen as the end of the production process rather than a separate step, and performance reviews reward thorough decontamination rather than short cycle time.

Some of the challenges Intel® faces in high volume movement of equipment may be unique to the semiconductor industry, where production processes seem to change rapidly in comparison to other industries with large chemical processing equipment. In addition, given Intel®'s strong reputation for EHS quality[29] [30], it may be that decontamination procedures require a change in perception rather than in specific techniques. The number of talented individuals working at Intel® should be able to devise successful processes, if properly rewarded for the successful rather than rapid performance of these tasks.

## *3.3 Results of Operational Analysis*

### 3.3.1 Crating Reuse

#### 3.3.1.1 Historical Crate Count Simulation

To perform the initial analysis of the feasibility of crate reuse, the intern developed a historical "count" simulation that would demonstrate the possible savings had a crating reuse program been in place for a given time period. Historical data was acquired from the warehouse database system ["WHDB"] going back to 1999. In the beginning of 2004, large-scale tool reuse resulted in a rapid increase in equipment storage. Based on this, the 2004 to mid-2005 time period was selected for evaluating movement of equipment and crate availability.

WHDB information alone was insufficient as it would not account for equipment moving from dock-to-dock (direct transfer from releasing to receiving site). Consequently, additional information was required. Data sets documenting tool reuse transfer dates for 2005 was acquired ["D2D"]. 2004 data for dock-to-dock was not available; however the significance of this data is estimated in a separate simulation excluding 2005 data. Because there was overlap between the WHDB and D2D, the two sets were programmatically reconciled to assure there was no double counting of tools. The following fields were relevant in constructing the historical analysis:

- Existing Fields
  - Asset storage date
  - Number of days in storage
  - Asset type (tool type)
  - Inventory status (in storage or no longer in storage)
  - Final disposition (Resale / Reuse)
- Additional Fields Created
  - Asset removal date [Calculated as Storage Date + Number of Days]
  - Reuse flag [Crate will not be recovered if tool is sold]
  - Lookup field from D2D into WHDB to flag any duplicates

The second data set required was the actual cost of the crate set. This data was determined through acquisition and evaluation of contract crating costs during the large-scale decommissioning of two fabs. This data was fairly detailed and prices could be determined for almost all relevant tools.

The third piece of data required was to determine the actual number of crates per tool. This was necessary because the WHDB recorded crate assets, but a single tool consisted of items stored in multiple crates. This number was determined by polling a warehouse field that recorded the largest number of crates used for a given tool entity type. That is, if a maximum of 15 crates were ever stored for tool type XYZ, it was assumed that the most typical configuration would be 15 crates. This was an overestimation, but was accounted for later by rounding methodology in the actual simulation tool.

Additional analysis was performed on the warehouse database to determine current and past average tool interment times, as well as standard deviations. This information was useful in demonstrating that not only was the amount of equipment increasing, but the average time in storage was increasing. Additionally, such analysis highlighted the challenges faced by warehouse personnel and made a compelling argument for further investment in inventory management systems.

The simulation was constructed in Microsoft Excel. Table 3-1shows layout and calculation fields. 25 tool types were selected for analysis, using the criteria of highest overall crating cost based on total estimated number of tools.

## Table 3-1 – Spreadsheet Mockup of Crating Reuse Simulation

| | Tool Egress by Type | | | | Crate Need by Type | | | | Crate Inventory | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | ABC | DEF | GHI | | ABC | DEF | GHI | | ABC | DEF | GHI |
| 1/1/04 | Calc1 | Calc1 | Calc1 | | Calc2 | Calc2 | Calc2 | | Calc3 | Calc3 | Calc3 |
| 2/1/04 | Calc1 | Calc1 | Calc1 | | Calc2 | Calc2 | Calc2 | | Calc3 | Calc3 | Calc3 |
| 3/1/04 | Calc1 | Calc1 | Calc1 | | Calc2 | Calc2 | Calc2 | | Calc3 | Calc3 | Calc3 |
| 4/1/04 | Calc1 | Calc1 | Calc1 | | Calc2 | Calc2 | Calc2 | | Calc3 | Calc3 | Calc3 |
| 5/1/04 | Calc1 | Calc1 | Calc1 | | Calc2 | Calc2 | Calc2 | | Calc3 | Calc3 | Calc3 |
| ... | Calc1 | Calc1 | Calc1 | | Calc2 | Calc2 | Calc2 | | Calc3 | Calc3 | Calc3 |
| | Cacl4 | Calc4 | Calc4 | | | | | | Calc5 | Calc5 | Calc5 |

Three separate calculations for each date period needed to be made for each tool type. Tool type is represented by three letter combinations ABC, etc.

Calc1 = Round ([All line items of type XXX in WHDB *exiting* one month prior or less than Date] / [Crates per tool]) + (Tools leaving releasing fab in D2D one month prior or less than Date)

*Sum all tools leaving the warehouse that are not going to be resold plus tools leaving releasing fab dock for direct transit to another site.*

Calc 2 = Round ([All line items of type XXX in WHDB *entering* one month prior or less than Date] / [Crates per tool]) + Tools arriving receiving fab in D2D one month prior or less than Date)

*Sum all tools entering the warehouse plus tools arriving to their new destination directly from another site.*

Calc 3 = If ((Calc1[Date] + Calc3[Date-1]) >= Calc2[Date], (Calc1[Date] + Calc3[Date-1] – Calc2, 0)

*If this month's available crate inventory and last month's running inventory exceed the need, Update the inventory to a positive number. Otherwise all crate sets will be used, and inventory is zero.*

Calc4 = Sum(Tool type XXX over all dates)

*Find the total available crate sets over the entire date range.*

Calc5 = Final Crate Inventory[Last Date]

*Find the remaining inventory at the end of the simulation.*

Calc6 = Calc4 – Calc5

*Determine how many of the available crate sets were reused.*

Calc7 = Sum over all XXX (Calc6[XXX] * Cost of Crate Set[XXX])

*Total savings of crate reuse*

There are some problems with this first simulation. First, it did not account for scenarios where a crate was needed before it was available. The granularity was one month, so everything that occurred within this month was considered the same. Consequently, Calc2 was modified to represent one month following Date, so that at the least crates would need to be in inventory one day and at most one month before they could be used. The difference between total savings in the two scenarios was about 9%, indicating that a time gap between availability and need of crates would not be a large concern historically.

However, in order to provide additional granularity, a weekly scenario was constructed where crates had to remain in simulated inventory for between 1-7 days before they could be used. This scenario was 0.07% less in total saving than the overlapping simulation, demonstrating very little difference between the less precise initial pass and a more precise method.

Finally, simulations were run evaluating top tools by crate set cost and number of tools. Savings under these separate two scenarios were about the same as in the weekly gapped scenario. Table 3-2 shows a comparison of results.

## Table 3-2 – Results of Historical Simulation

| Historical scenario | Savings as a % of total crate spend |
|---|---|
| Month-to-month overlapping | 22% |
| Month-to-month gapped (no overlap) | 20% |
| Month-to-month gapped not including dock-to-dock | 20% |
| Weekly gapped | 22% |

#### 3.3.1.2 Projected Simulation

After the historical simulation showed promising results for a crating reuse program, the development of a projected simulation for the time period 2006-7 commenced. Roughly the same methodology in terms of calculations could be used, however different database systems needed to be queried in order to access projected data.

Two systems were used for this simulation. The first is a database ["DB1"] of estimated tool move-out dates. Initially there was significant difficulty in accessing this data, as the primary access mechanism was through an OLAP "cube" which was too slow for a large data extraction. Later access was obtained for direct database connection. The second is a database ["DB2"] of equipment capacity planning which specifies when equipment is expected to be free of need for manufacturing, as well as when new equipment will be needed. This database was initially accessed through Microsoft Excel exports, which were extremely cumbersome because text and data processing had to be added in order to format the results for the simulation. Later, direct access to the database was acquired, allowing for easier handling.

Based on the capacity free dates in DB2, roughly 50% of the equivalent tools in DB1 had move out dates listed. Therefore, it would be assumed that the results of the simulation would underestimate the demand for crates (because of lack of forecast data), while fairly accurately estimating the need for crates. Essentially identical calculations were used for the projected simulation, except using the expected need and availability dates in DB1 and DB2, respectively. A weekly gapped scenario was used to approximate crate transit time and allow for slippage. That is, crates would need to remain in storage between 1-7 days before they could be "used" in the simulation.

One change over the historical simulation was that a slightly different model was used for selecting the top 25 tool types. The simulation was run for the top 75 tool types by crate set cost, and then the top 25 were selected based on the maximum savings. Best practice selection process in a crating decision support tool will be discussed in Section 4.1.1.

Simulation results are as follows for 2006-7. Total expenditure indicates the total crating cost for the specific data set indicated.

**Table 3-3 – Results of Projected Simulation**

| Metric | Data Set | | |
|---|---|---|---|
| | Top 25 tools by savings | Top 25 tools by crate cost | Top 75 tools by crate cost |
| Total expenditure (normalized) | 1.0 | 0.83 | 1.5 |
| Total savings (% of total expenditure) | 52% | 39% | 35% |
| Crates unused (% of total expenditure) | 28%<br>44 sets | 70%<br>46 sets | 46%<br>84 sets |
| Maximum projected savings assuming all crates are reused (need extrapolated from 50%, % of higher total expenditure) | 32% | 43% | 33% |
| Average crate set inventory | 36 | 32 | 58 |
| Maximum weekly crate set inventory | 44 | 34 | 84 |

These metrics were evaluated under the assumption that crate set inventory would need to be minimized, % savings would be a key factor in determining whether upper management would approve a crating reuse plan, and whether a decision support tool could help improve the probability that high % savings could be achieved.

Data has been normalized for confidentiality purposes, however, to give approximate size comparisons, the difference between an optimized crating reuse program and one based on the top 25 most expensive crates is roughly $0.5M. This is a compelling argument not only for a reuse program, but for investment in a decision support tool (DST) that will allow for better resource planning. However, limiting that advantage is the assumption that need data only reflects 50% of total. As need increases, and predicted % crates reused increases, simply choosing the most expensive crates will result in better savings.

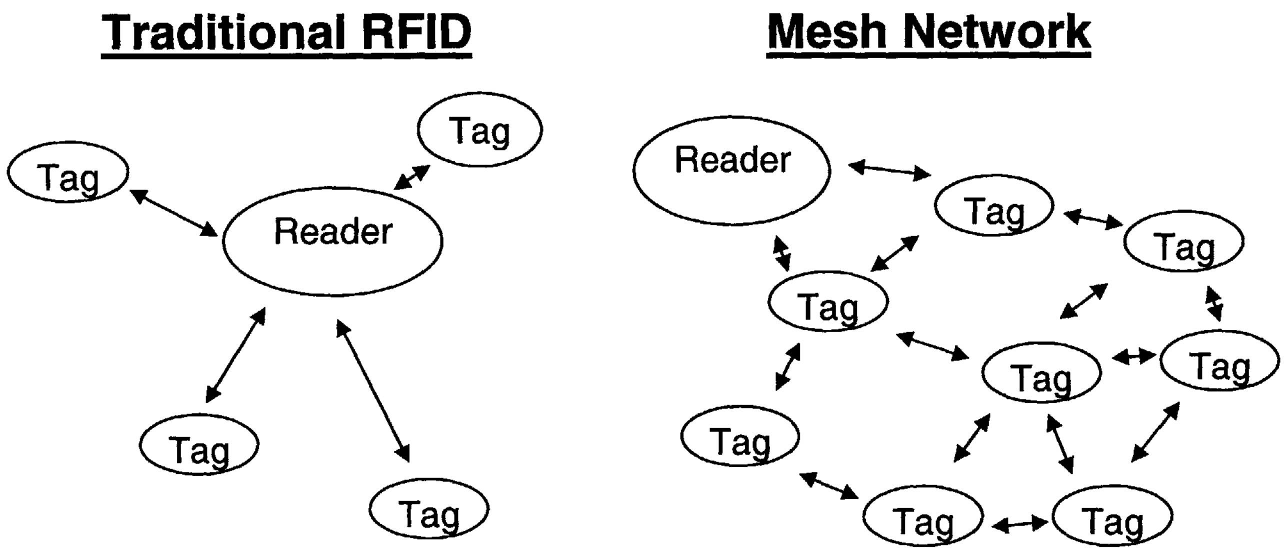
Systems architecture of a DST will be discussed under recommendations in Section 4.1.1.

### 3.3.2 Auto-Tracking, RFID, and Inventory Systems

RFID (Radio Frequency ID) has been around since the 1970's and is a proven technology for wireless communication between a "tag", or small component attached to an asset, and a handheld or stationary tag reader. The tag allows for unique identification of assets and a faster inventory management process. Cost has been the primary limitation for widespread adoption, with technology standardization and privacy concerns the other major limiting factors[31]. Large retailers such as Wal-Mart have changed the industry significantly by pressuring suppliers to undertake tagging of shipped pallets. These changes will likely lead a decrease in prices for RFID implementations, and further adoption of the technology. Passive RFID systems use the power of radio waves from the reader to respond to a read event, while active RFID systems have their own battery[32].

In addition to the differences between manual, barcode and RFID systems, two additional technologies are worth mentioning which may further extend the capabilities of automated asset monitoring systems. The first, sensor networks, allows for the attachment of sensing technology to unique identification systems. This permits the detection of anomalous states of temperature, humidity, current, or shock. The second technology is mesh networks, which changes the paradigm of RFID by allowing tags to talk to each other. This may overcome some of the distance limitations and allow for autonomous self-repairing networks with no single point of failure. A comparison of traditional RFID to Mesh networks is displayed in Figure 3-1.

**Figure 3-1 – Traditional vs. Mesh Auto-ID Networks**




Additional concerns for implementation of an RFID or sensor network may be the durability required of the tag (most tags can survive a 6 foot drop), battery life required, available space for the tag (tags are typically as small as a stick of gum for passive RFID, and as large as a pack of cards for active RFID) and potential interference of active-type tags with existing wireless networks. Some tags available today can even take advantage of existing wireless data networks using the 802.11b standard.

Based on interviews[33] and market investigation, Table 3-4 was developed to compare the relative advantages of various technologies against a baseline of manual processes in the warehouse inventory management process.

Based on the relative factors listed in Table 3-4, the challenge was then to determine the relative advantages and disadvantages of bar-coding vs. RFID. Both were competitive in comparison with a manual process, but had different aspects which would make them more or less suitable. Table 3-5 compares the two technologies and draws in additional, strategic factors to the consideration of barcodes vs. RFID.

## Table 3-4 – Technical Overview of Inventory Management Systems

| | Technology Type, by increasing automation | | | | | |
|---|---|---|---|---|---|---|
| **Metric** | **Manual** | **Barcode + Handheld** | **Passive** | **Battery Assisted Passive (BAP)** | **Active RFID** | **Active RFID + Sensors** |
| **Read Distance** | <10cm | <10cm | 10mm-1M | Up to 30M | Up to 60M | Up to 60M |
| **Battery Life** | N/A | N/A | Forever | Long | 3-7 Years | <5 Years |
| **Information Captured** | Asset ID | Asset ID | Asset ID + Stored Info | Asset ID + Stored Info | Asset ID, Stored Info and Location | Asset ID, Stored Info, Location and Sensor Data |
| **Read Speed (crates/minute)** | ~0.4[34] | ~3[35] | ~3 | ~12 | Instantaneous | Instantaneous |
| **Limitations** | Line of Sight<br>Accuracy<br>Height | Line of Sight<br>Height | Height | % read<br>Interference | Physical and wireless interference<br>Battery Life | Physical and wireless interference<br>Battery Life |
| **Material Cost/Crate** | $.10 | $0.10 + $2000/reader | $0.50 + $2000/reader | $24[36] + $2000/reader | $65[37] + $5000/site | $200[38] + $5000/site |
| **Reusable?** | No | No | Yes | Yes | Yes | Yes |

Finally, evidence developed through interviews[39], discussions during 6D WG meetings, and through the process of acquiring data for analysis shows that the lack of integration between major data sources is currently a serious drain on resources. Legacy systems with limited maintainability create the risk of data loss and dependency on key personnel. Manual reconciliation of data creates the potential for errors, impacting the efficacy of the tool reuse and resale programs. Labor wasted by manual data entry could be expected to rise with continued storage of assets, and may be roughly equivalent to the expense of integrating key inventory systems.

**Table 3-5 – Comparison of Barcode vs. RFID**

| | Advantages | Disadvantages |
|---|---|---|
| **Barcode** | • Mature technology<br>• Available now in tool audit system<br>• Greatly reduces cycle count times<br>• Handheld readers are inexpensive<br>• No major infrastructure changes | • Still a manual count process<br>• Line of sight for scanning<br>• Height of stacked crates |
| **RFID** | • Major increases in speed of inventory<br>• May be additional "unseen" benefits<br>• Reduces time employees are in warehouse<br>• Potential to locate assets<br>• Proof of concept keeps Intel® ahead of the curve | • Read rates not 100% all the time<br>• Requires major investment in technology and infrastructure<br>• Learning curve<br>• Risk of "lock-in" to non-standard technology |

### 3.3.3 Decontamination Improvements

Due to the risk associated with decontamination problems, a lot of attention was directed throughout the internship towards methods of improving procedures. These methods included improved knowledge management and centralization of checklists, development of single points-of-contact for escalation of issues, and increased awareness of challenges. However, a number of additional challenges came to light which might not be met as effectively by a continuous improvement model.

Appendix B shows a matrix of the 6D process with risk and rework highlighted in increasing levels of hazard. While only the 1D and 5D processes are displayed in this graph, one of the immediate challenges visible is the long cycle time between error creation in the 1D process, and error discovery, which sometimes will not occur until 5D or 6D. This challenge, in addition to the long timelines involved, shows that improvements will also take a long time to filter through the system.

Given the numerous risks associated with problems in the decontamination stage, including damage to equipment or potential chemical exposure to employees, the intern's recommendation at mid-point in the internship was to look at other models of addressing the challenge of reducing decontamination problems. This was based on three factors:

- The long cycle time between error creation and discovery
- The challenges of disseminating decontamination knowledge throughout the company
- The associated costs of decontamination errors

The model suggested at that point was to add additional staff in as large quantities as necessary to immediately reduce the errors to zero, based on repeated double-checking and work verification. When errors were reduced and verified at zero for an extended period, say one to two quarters, then the company could investigate scaling back the labor invested in the process.

The cost of rework (i.e. re-decontamination with special teams), as evaluated through interviews with key EHS employees, was calculated to be a fraction of the cost of the loss of one tool, possibly as low as a tenth of a percent. In addition, the cost of "rework" on all tools decommissioned in a year would still be some 20% of the cost a tool lost to chemical or physical damage. Cost does not even take into account the ancillary benefits of drastic reduction of risk to employees. Thus, even if every tool was reworked immediately following the initial decontamination phase, the reduction in cost to the company would still be less than the cost of one lost tool. As evidenced by the proceedings of the 6D WG, the risk of tool loss was still significant for tools entering the 6D process at the end of 2005.

An additional challenge highlighted through interviews with employees was the challenge of managing the number of contract employees ("green badge") at Intel®. There is a much higher attention to safety and procedural improvement among full time employees ("blue badge") than among the contract labor staff. However, both groups have equivalent opportunities to expose Intel® to both financial and human risk through substandard work practices. A number of blue badge employees indicated the importance of monitoring contract workers, both to decrease potential green badge safety incidents and to assure protection from damage to Intel® property.

Finally, because decommissioning of equipment is a cyclical rather than regular activity, the challenge of staffing experienced decontamination teams at each site was evident. Fluctuations in need for staff involved in installation and de-installation of equipment had resulted in reluctance on the part of employees to undertake these roles. Either assurance of regular work, investigation of overlapping roles and responsibilities, or a change in the labor model seem necessary to assure that employees remain experienced in the 6D process.

### 3.3.4 Capital Asset Inventory Reduction

One of the key discoveries early on in the internship was that inventory levels had increased and maintained at high levels for the past two years, as seen in Figure 2-4. This led to the question of inventory cost. Inventory cost can be categorized by the following measures:

- Cost of capital tied up in equipment in storage
- Storage costs (across all sites for space)
- Disposal cost (obsolete equipment must often be disposed of as hazardous waste)
- Inventory management cost, including labor and inventory counts
- Asset value loss, due to obsolescence / depreciation

While these factors are most likely significant, it was not immediately in the scope of the project to determine the factors with greater granularity. However, models[40] do exist for how to analyze keep, sell and discard decisions. As of early 2006, this year's Intel® 6D internship will involve greater determination of costs, as well as opportunities, in more rapid reduction of inventory in Intel® warehouses.

### 3.3.5 Cycle Time Analysis

There were a number of challenges in performing a cycle time analysis of the 6D process, which was originally requested by one of the 6D managers. The purpose of this analysis was to evaluate whether the current estimate of transfer time, 8 weeks, used in planning equipment utilization, was valid and would assure that equipment could be transferred between factories without jeopardizing the ramping of new production.

One challenge was the difficulty of access to data. Data was first accessed through an OLAP "cube" called Insight, a data analysis engine by Databeacon. This engine was not capable of providing a full database dump, or export of all information. The second challenge was "ghosting," or remnants of prior, incorrect entries remaining in the "cube" system after the backend database had been updated. The third challenge was lack of information, as at least one fab had not entered information into the system during a large decommissioning of equipment, but instead had captured the information on paper. At the time, it seemed unlikely that this data would ever be entered, and the value of tracking down and entering the data seemed questionable. The fourth challenge was that no data existed on actual transit times between sites. While transit companies were bound by service level agreements (SLA's) specifying how long transit should take by different modes (air, sea, land), real times were not captured.

The data export and the ghosting challenges were finally addressed through direct database access. However there was no resolution to the challenge of missing data, and the validity of the results could easily be called into question. Because of the lack of transit times, analysis encompassed 1D through equipment move out. Move out occurs typically mid-way through the 3D process, with additional demolition necessary to fully remove the infrastructure required by the tool.

The results showed a large degree of variability through the process, both at a high level as well as at a tool-specific level. While much of the equipment was completed within the timeline specified in equipment planning, not all was. Without evaluating each tool on a line-by-line basis, it would be difficult to understand the root cause of this large degree of variability. In some cases, where the cycle time exceeded several months, it seemed likely that the problem could be data entry or a lack of closing of records. The only way to fully reconcile this information would be to evaluate every piece of equipment and cross-reference with the WHDB and D2D databases. Even then, it would be difficult to establish what percent of the data was accurate.

### 3.3.6 3-Dimensional Charting in Excel

During the crating reuse analysis, the intern discovered some of the limitations of graphing in Microsoft Excel. What was desired was a 3-dimensional (3D) graph which could communicate the following information:

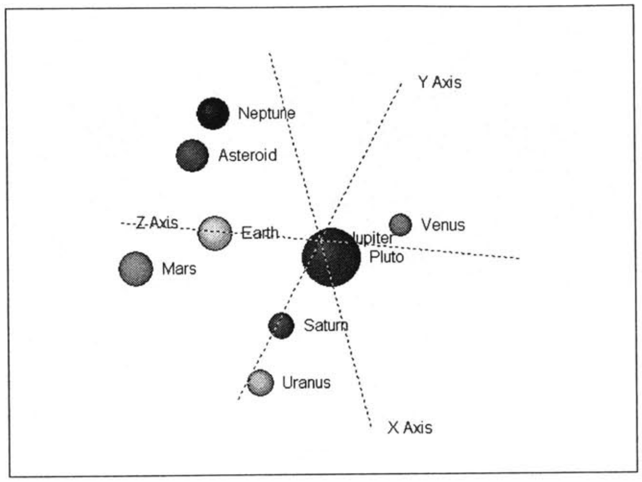
- Average interment of a tool in storage
- Crate cost of a tool
- Historical / projected number of tools

Bubble charts allowed some ability to show this information, however it was challenging to scale the relative importance of each factor using this tool.

Using an excel spreadsheet created by Andy Pope[41], the intern created an extension tool using bubble charts to allow for rotation and display of information within Excel in 3D. Though the tool was not used as part of a presentation of information, it may be useful for individuals looking for a portable way to graph Excel data in 3D.

The tool uses geometric calculations, a slide-bar, and an automated GIF[42] image exporter to allow for patching together of animated rotations of graphic data. Figure 3-2 shows a single export from the tool with simulated data. An animated graphic file will also be included. A user would need some experience in Excel in order to make effective use of the tool.

## Figure 3-2 – Excel 3D Graph Example



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# Chapter 4 Project Recommendations

## 4.1 Recommendations

The recommendations that developed from the internship are discussed in this section, as well as current level of acceptance within the company. Recommendations were presented to 6D managers, KM staff, and other stakeholders during the concluding week of the internship.

### 4.1.1 Crating Reuse

The intern recommends that Intel® move forward with an investigation of the remaining logistical challenges of a crating reuse program. This means determining the following:

- Cost of crate storage
- Cost of transportation
- Estimated transit times for crates between sites
- Administrative costs of running a program
- Best labor model (internal / outsourced) for running a program

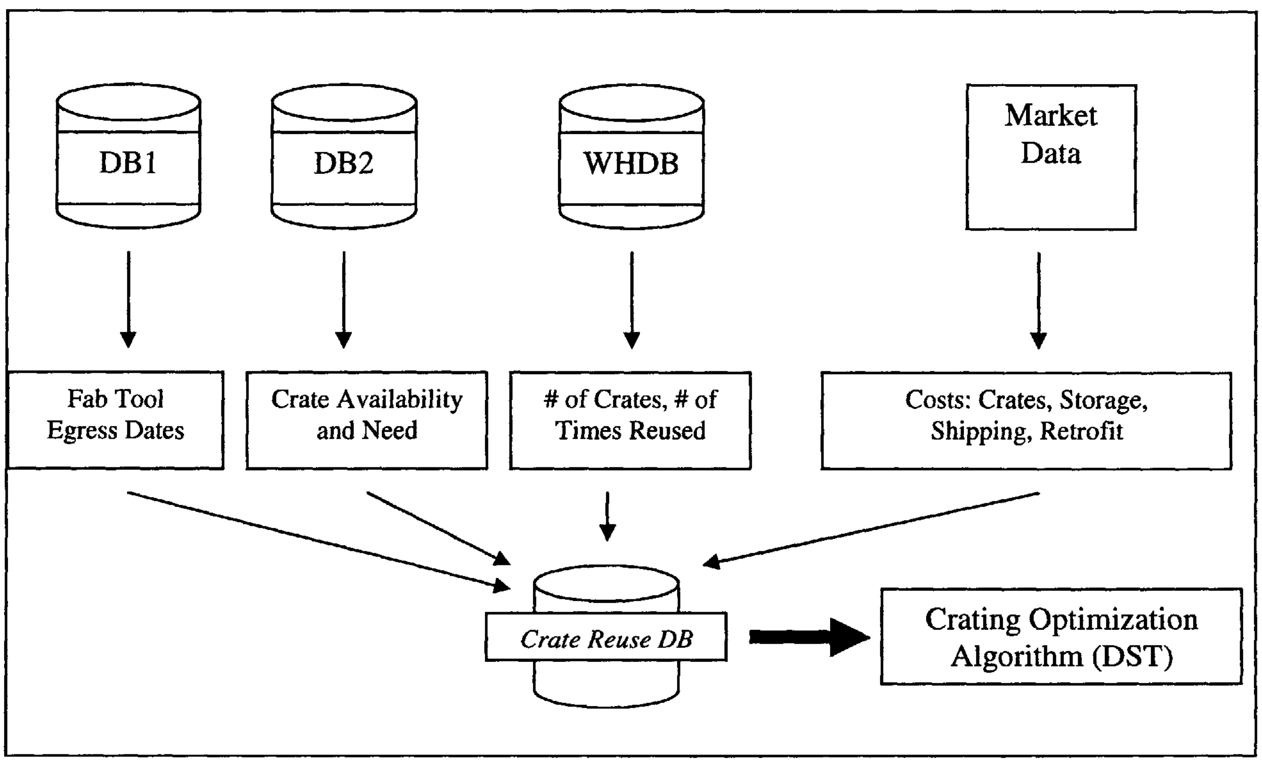
Based on the information listed, the cost calculations of the simulation could then be adjusted to determine the most cost effective method to engage a reuse program, and the optimal configuration in terms of which crate sets to save.

Furthermore, the intern recommends the development of a crating reuse decision support tool (DST), which will allow key managers to plan the highest ROI for the program based on projected need and availability. Figure 4-1 depicts the information architecture of a crating DST, including proposed use of current databases as well as the development of a small "Crating Reuse Database" to contain market information as well as connections to relevant Intel® data sources.

In addition to the data accounted for in simulation outlined in Section 3.3.1.1, the Crating DST should include data about the total number of tools in all Intel® facilities. This would be used to evaluate the maximum number of crate sets to be saved at any time, in the case that a large number of tools were destined for parts harvest or scrap. The database would also contain information about the number of times a crate was used, and a record of crate inventory. The WHDB could also be used in this instance to store relevant data. Based on research performed by a 6D sub-team, crates should be able to withstand a certain number of reuses. The exact number can be further determined through research and testing[43], and crates can be preferentially selected for more strenuous tasks, such as shipment, when new, and less strenuous tasks, such as long term storage, when used.

Because the Crating DST is a tool for Intel®ligent choice by managers, it should allow for specific selection of tools that have high value but for which data on need does not currently exist. This will allow for saving high ROI crates even though need is not proven by demolition forecasting.

## Figure 4-1 – Crating DST Information Architecture



The intern further recommends that Intel® strongly examine the relevance and accuracy of the demolition forecasting database (DB1) and evaluate how to better match data capture with relevant process times. More attention to this database would allow better forecasting for not only a DST, but for important labor functions such as warehouse planning. In the future, it would allow for data-driven analysis of 6D cycle times, and further analyses of correlations between cycle times and error rates.

The Crating DST should be developed by a programmer or team of programmers with optimization of processing speed in mind. While Excel is a useful tool for prototyping, the necessary post-processing on data and slow calculation speeds of the current prototype makes the tool challenging to use for managers. A 2-3 month project should be sufficient for a functional DST that would allow for efficient crating reuse to begin. Relevant data on storage and transport costs should be evaluated in order to better tune the optimization algorithm.

Based on evidence of choice methodology in the absence of a Crating DST, the investment in a decision support tool would more than pay for itself in terms of reduced administration and additional avoidance of crating cost. A Crating DST should allow for better planning[44] in the demolition process, improve transit times, and better help guarantee timely installation and ramps. Incidental evidence from meetings has demonstrated that planning for crates is still not integral and standardize, and so decision support should reduce occasions where crates are not available for equipment.

### 4.1.2 Auto-tracking and Database Systems

There are two significant opportunities for improving inventory management of capital assets in the warehouse, asset tracking and integration of database systems.

The intern recommends that Intel® strongly investigate the overall costs of implementing a BAP RFID system in the warehouse. While more expensive than leveraging current barcode technology, it would have a series of additional benefits such as reduction of risk to employees, faster inventorying, and potentially faster location of equipment.

RFID technologies have not yet fully standardized, but the advantages to early institutional understanding of the risks and benefits of the technology outweigh the hazards of premature adoption. Based on investments by Intel® in sensor technologies and internal development of similar products, Intel® must also invest in understanding the potential non-obvious benefits to the technology. Research[45] [46] indicates that some of that knowledge may only be obtained after a proof-of-concept has been achieved, and ROI analyses may not reveal some of the hidden benefits of implementation. Management of Intel®'s capital assets should be an ideal test case for the capabilities of RFID and auto-tracking.

In addition, as Intel® changes focus to solutions over products[47], understanding the enterprise applications of technology in inventory management will be a significant competitive advantage against other solutions providers.

The second opportunity for Intel® is to further integrate databases so that end-to-end management of assets does not need to be supplemented with manual reconciliation of data. Besides the obvious expenses in labor, the potential for error and misplaced equipment is too great to continue reliance on disparate data. The importance of tool reuse has been demonstrated in terms of cost avoidance and competitive advantage. Additional investments must be made in the information management infrastructure to allow the 6D process to be optimized.

By engaging in an end-to-end integration of inventory management, Intel® should be able to realize multiplicative savings and advantages over implementing only a tracking solution or only a database integration. Capital asset management should not be the realm of dark, crowded and forgotten warehouses, especially with the importance of reducing capital expenditures. Investing in this capability should allow for more rapid turns of capital asset inventory, reduction in overall inventory size, and generation of surplus cash for investment in competitive projects.

### 4.1.3 Decontamination Improvements

Recommendations for improvements to the decontamination process are similar to those made midway through the internship. Intel® should dedicate larger personnel resources to decontamination until problems are reduced to zero. In addition, decontamination should be re-verified before equipment leaves the fab.

Given the large cycle times between decontamination error creation and discovery, as discussed in Section 0, continuous or incremental improvement models will be more expensive and risk prone than immediate "brute force" or high resource allocation methods. Once problems are reduced to zero and Intel® draws significant attention internally to decontamination, labor can be scaled back, assuring that training and knowledge dissemination infrastructure has been well established at each location.

The solution methodology can take the form of additional double-checking personnel at each site, or specialized teams that move from site-to-site doing quality assurance with local domain experts. As discussed in Section 3.2, long term changes will likely come about only when tool engineers perceive the decommissioning process as part of the originating production process, rather than additional labor which must be completed in order to ramp a new process. In the fab, performance reviews must be calibrated to reward successful decommissioning, not necessarily rapid decommissioning.

### 4.1.4 Future Internship Projects

During the internship, the intern became aware of a number of opportunities for projects based on interviews and operational analysis. In many cases the projects could not be undertaken due to the constraints of time or agreed-upon scope of the internship. These opportunities are broken down into continuing and new projects.

#### 4.1.4.1 Continuing Projects

- Further analysis of logistics of a crate reuse program
    - Development of crating decision support tool
    - Examine opportunities for equipment fixtures
- RFID / Auto-tracking in the warehouse
    - Extensive breakdown of costs and development of a proof-of-concept program

    - Determination of timeline and budget for large-scale implementation
    - Research potential hidden benefits of program
- Decontamination KM and Training
    - Extensive interviews into BKM's for knowledge capture
    - Evaluate how to best construct a tight-loop knowledge capture and training program

#### 4.1.4.2 New Projects

- Database integration of inventory systems
    - Evaluate ROI on further integrating key systems
    - Establish costs and timeline for information management
- Decision support system for tool end-of-life process (chosen as the 2006 6D internship project)
    - Timing / trigger points when to sell or keep tools
    - Extremely large potential impact on available cash
    - Opportunity to further reduce inventory and control tool scrap costs
- Integration of 6D with Sort and A/T
    - How to integrate 6D processes with other manufacturing arms of Intel®
    - Logistics and risk assurance for international locations

## *4.2 Change Management*

### 4.2.1 Process Control and Goal Alignment

As demonstrated by the cycle time analysis, the 6D process has a number of challenges in achieving control over variability in the system. There is some perception that it is too early for 6D to engage in operational analysis with a goal to determine averages and standard deviations. However, even if the goal is to control the process at a higher than desired cycle time, the goal of process control should be undertaken sooner rather than later.

A number of employees are clearly working towards those means through design of extensive checklists and engagement of staff at the different sites. Analysis and presentation of numerical data is a key method of attracting attention and support to a previously ignored work flow. It will be contingent on the 6D leaders to convince working group members that quantitative evaluations of progress will be critical in developing internal motivation to change at Intel®.

Continued success at controlling the process cannot be achieved by the 6D team alone, but must be engaged at a higher level, such as by that of fab managers. In the case of decontamination, group leaders must be made aware of the importance of 6D processes in protecting capital assets. Effective leadership from upper management is the only realistic way that groups with different performance goals will be able to work together. Finance can and has played some role in creating disincentives for negligence, but a greater role may be played by highlighting the real loss in the system and helping 6D team members find solutions with effective ROI. Otherwise efforts may be propagated in less effective directions due to perceived rather than proven problems.

### *4.3 Long-Term Goals*

As 6D matures, the long term goals will certainly evolve from that of damage control and large-scale change to that of continuous improvement. There are several factors which should contribute to long-term success in maturing the 6D process:

- Effective communication of the importance of capital assets to Intel® employees
- Maturation of knowledge and information management
- Reduction of equipment storage through sales and effective deployments
- Strong attention to the significant costs associated with tool transfer

Operational analysis should reveal the greatest points of weakness or loss in the 6D process, and serious attention should be made to determining the real cost of ineffective or outdated methods. The continuous challenge is one of being proactive rather than reactive to the results of the multiple steps preceding a tool's entry into 6D.

## *4.4 Recommendation Acceptance and Progress*

As of late December 2005, a number of developments had occurred in regards to the different projects recommended.

The crating reuse analysis was received and accepted by the CS 6D manager, and a presentation was developed for review by the VF team who would have approval over such a project. In addition, employees at Intel® had begun to research the associated costs which were not calculated as part of the analysis, such as storage and transportation. Initial estimates show the costs to be negligible in comparison with the savings. The following steps would be to obtain managerial and group approval, and to request proposals from a 3rd party logistics provider who would be responsible for managing a crating reuse program. In addition, it is likely that a TME group would need to become involved if development for a Crating DST is approved.

Discussion of RFID generated significant interest from several parties. The KM group has expressed interest as part of a continuing effort to improve knowledge and information management. Intel®'s logistics group is interested in RFID in the warehouse as a potentially valuable proof of concept for the technology. Warehouse managers are excited about RFID as a way to reduce labor time and improve the accuracy of cycle counts and inventory information. Currently there are plans for developing a proof of concept opportunity for this implementation.

At the last meeting of the 6D WG in 2005, a plan was proposed to significantly change the labor model for decontamination, moving to a partially outsourced specialist team that would assist tool engineers in the 1D procedure, and help accumulate best practices across multiple facilities. While this model was not necessarily direct result of internship recommendations, the intern hopes that through identifying the problems around a long cycle time process, 6D managers obtained some insight as to potential solutions for addressing these challenges.

# Chapter 5 Conclusion

## 5.1 Approaches to Problem and Solution Determination

The flexible approach to understanding the 6D process, utilizing interviews, basic financial analysis, and benchmarking, helped winnow a large problem set to a more manageable one, where known and understood operational tools could be applied to generating potential solutions. This might be contrasted to a focused initial approach, which might not have revealed the complexities of factors such as the inability of databases to synchronize information important to multiple stakeholders. In addition, by interviewing a large number of stakeholders from multiple areas of Intel®, a better understanding of interactions could be constructed that would allow for discovery of problems outside the context of the internship.

External benchmarking is a continuous challenge and there are not conclusive studies that show the benefit of comparing quantitative information across industries. At the same time, benchmarking against competitors may be a high-risk proposition, especially when the process in question is of strategic importance to a company. An alternate method which may be very useful is brainstorming or idea generation by internal "domain experts". This could be an extension of a knowledge management infrastructure, and would need to be carefully managed to assure an effective environment.

Because of the organizational challenges of introducing new ideas, a common forum to discuss problems and solutions in a non-critical manner might allow for greater innovation. As an organizational outsider, there is the advantage of not being fully invested in internal politics, performance measures, and structural "silos". Understanding how to connect disparate sources of information, especially tacit knowledge, will likely be an ongoing challenge for large organizations.

## 5.2 Focusing a Program Using Operational Tools

Once a basic understanding of a process is in place, operational tools such as value stream mapping, workflow analysis and data simulations can be extremely useful in helping an organization understand opportunities for improvement. Combined with pro forma financial projections, operational tools can further direct a program towards maximizing the ROI based on limited labor and resources.

However, ROI analysis is not the only solution space for approaching a problem. In cases where environmental risk to personnel is a factor or new technology is not well understood, ROI analysis may be inconclusive or inapplicable. Understanding the cumulative effect of quantitative and qualitative factors can help frame a more optimal solution. In these cases, an organizational understanding of qualitative risks and benefits is important. Visual or non-standard techniques may be useful to communicate the importance of hidden factors.

## 5.3 Decision Support and Process Optimization

While decision support systems based on data mining may not lead to full process optimization, there is clearly a benefit to their implementation. Connecting managers with important data should allow for better decision making and more compelling cases for undertaking process change. In an organization where a great deal of data may be saved, but essentially "unavailable", decision support tools can bridge the gap between missed opportunities and significant ones.

In a long-cycle-time process with decentralized users and no direct hierarchy, continuous improvement may not be the ideal method to achieve best results in a given time period. Managers must also look to business process re-engineering where significant and damaging events will continue without intervention.

## 5.4 Knowledge Management as part of a Manufacturing Process

The 6D program has shown the real importance of knowledge management, the importance of connecting KM with real workflows[48] and the long-term challenges to effective implementation of a KM and training infrastructure. In many cases an organization may have captured relevant knowledge, but it may not be in a form that is available or utilizable by employees who need it. In addition, tacit knowledge may be most effectively communicated by verbal means or learning-by-doing. Managers will need to understand the options not only on the KM side, but the training side as well. In an organization with a highly mobile workforce, such as Intel®, the importance of communicating KM capabilities to managers is even more important. Effective, defined programs such as 6D may be the best way to develop awareness and organizational capabilities in KM, compared to overarching solutions with no real defined or expected outcome.

### *5.5 Consensus and Organizational "Pull"*

As knowledge management can help uncover hidden capabilities in an organization, interviewing as a form of problem determination can also help develop organizational "pull" for a process or organizational change. Especially for an outsider with a limited time frame with which to build consensus, drawing from employee defined problems proved more effective than a self-generated approach. In addition, by the conclusion of the internship, it was evident that even if the recommendations were not fully implemented, there was a greater organizational awareness of challenges common to several people. In contrast to the proposition of cycle time reduction, presentations on waste reduction by crating reuse and auto tracking technologies were much better received; the audience from which the problem was defined was larger as well. For a change agent, understanding the effectiveness of these factors is a key learning in future projects and endeavors.

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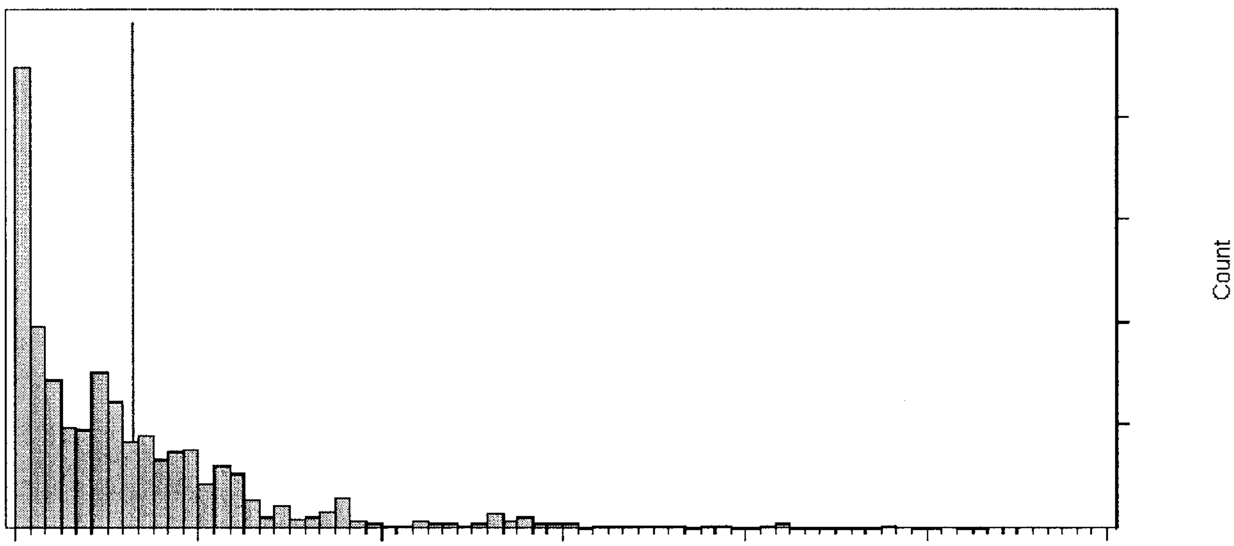
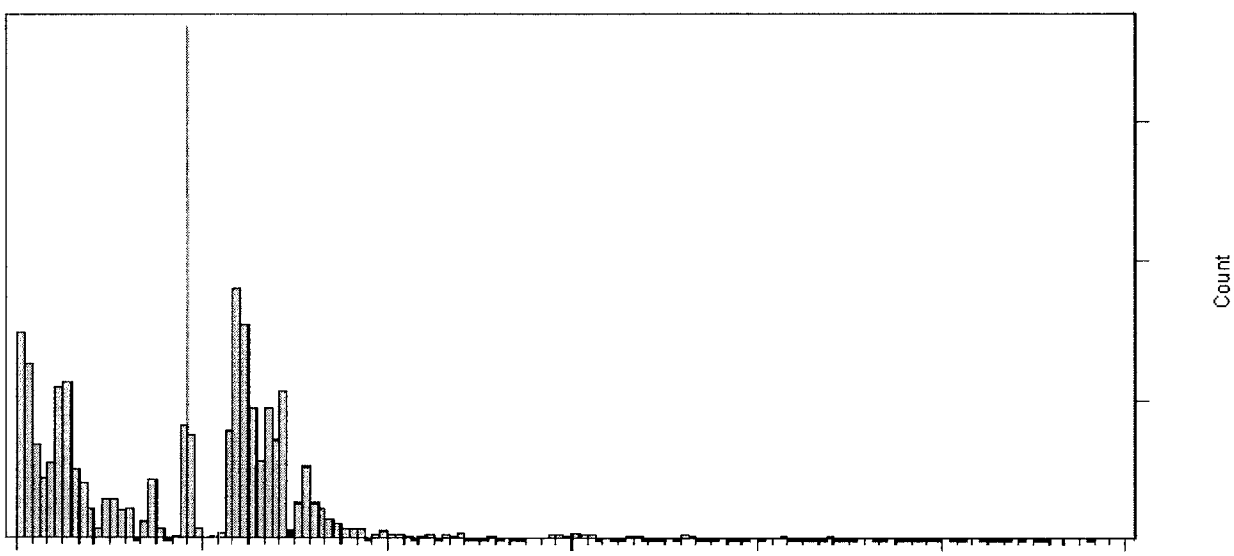
# Appendix A – Graphs of Historical and Current Tool Interment Times

These historical and current snapshots of average warehouse interment of capital assets highlight the increasing average time of storage over comparable timelines. Continued increase in average interment times will challenge warehouse management systems. The y-axis is not to equivalent scale between the graphs.

**Historical and Current**



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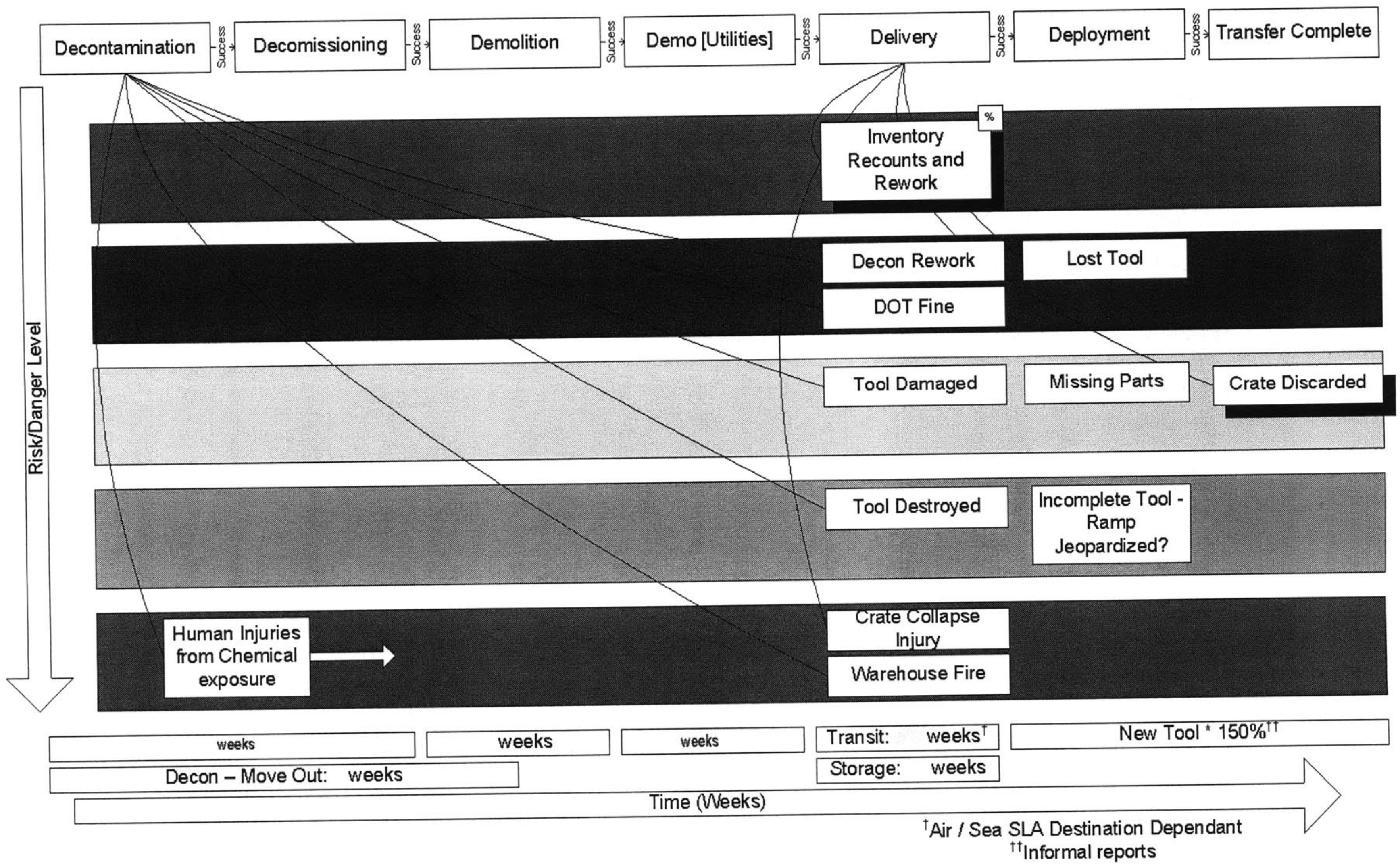
# Appendix B - Risk and Rework in the 6D Process



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# Appendix C – Endnotes

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