Challenges Faced by a Global Team: the Case of the Tool Reuse Program at Intel®

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ABSTRACT

The semiconductor industry is characterized by a high cost of capital equipment and fast change in process technology. Therefore Intel ® Corporation as the world's largest semiconductor company has a significant advantage over its competitors in reusing its semiconductor equipments. Not only may the financial impact be considerable, but also Intel ® Corporation can see benefits in process development, equipment reliability, and training.

However, demolishing and reusing tools do not go without major difficulties: complexity of the equipments, safety concerns because of the chemical used, reliability of the tool when reused. Consequently, in late 2004, the 6D Program was initiated to preserve Intel's assets during transfer from decontamination through deployment (reuse, resale, part harvesting, donation or scrap) using safe, effective procedure and business processes. In less than 3 years, the 6D Working Group has created procedures, checklists and trainings to assure "best-in-class" performances.

This project was set up to support the 6D Working Group's improvement strategy by analyzing gaps that may exist in the system. Especially, the thesis analyzes the challenges faced by the 6D Working Group (a global team) to influence and standardize local practices. By using game theory analysis, recommendations are made to change incentive policy. A new set of metrics is proposed to drive accountability of the sites and foster process improvements. Finally, using a system dynamics approach, the thesis offers insights to answer the question of the adequate level of standardization of processes.

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Introduction

This thesis is the culmination of a six-month internship at Intel Corporation's Fab 11/11X located in Rio Rancho, New Mexico. The 6D Working Group sponsored this project as part of an ongoing effort to improve process efficiency.

1.1 Project overview

The present project is the third MIT-Leaders for Manufacturing (LFM) internship working on the 6D Program at Intel®. The objective of the 6D Program is to ensure that Intel's Fabs use safe, effective procedures and business processes to transfer assets from the factory to its final destination (reuse, resale, part harvesting, donation or scrap.) It involves seven steps: Pre Demo activities (audits, preparation of the procedures...), Decontamination, Decommission, Demolition, Demolition of Utilities, Delivery and Deployment.

Intel® is a multi-national company with decentralized manufacturing processes over multiple sites. On a global basis, the 6D Program is designed and coordinated by the 6D Working Group, and at a local level, tool demolitions and reinstallations are executed by dedicated teams. Therefore both the 6D Working Group and the local Fabs have to work hand-on-hand to improve the existing procedures and deliver consistent results. However, many barriers impede standardization and process sharing. These barriers may be complexity of the tools, existing local practices and misalignment of incentives. The present thesis analyzes some of these barriers and provides recommendations to build accountability of the Fabs, foster standardization of the procedures and improve communication between sites.

1.2 Thesis Overview

This thesis is divided into three main parts.

Chapter 2 discusses the asset management at Intel®. This part provides an overview of the tool allocation process and presents a decision tool to choose between harvesting and selling a tool. Finally the 6D Program and its high level work flow are detailed.

Chapter 3 describes the organization in place to implement the 6D Program. Especially this part highlights the challenges faced by a global team, the 6D Working Group, to influence and standardize local practices. Using a game theory analysis, the author advocates that the lack of accountability of the sites and communication between sites may be attributed to the current incentive structure. A revision of the policy is proposed.

Chapter 4 explores different process improvement frameworks (Lean, 6-sigma, theory of constraints, learning organization) to improve the 6D Program. A set of metrics is proposed to measure and align process improvement toward strategic objectives. Finally the question of the adequate level of standardization is tackled with a system dynamics model.

2 Asset Management at Intel®

This Chapter discusses the asset management at Intel®. First, we discuss on the motivations of an efficient tool reuse program, and then we provide an overview of the tool allocation process. A decision tool to choose between harvesting and selling a tool is presented. Finally the 6D Program and its high level work flow are detailed.

2.1 Motivations

"The semiconductor industry and our operations are characterized by a high percentage of costs that are fixed (i.e. facility construction and equipment, research and development, and employment and training of a high skilled workforce) or otherwise difficult to reduce in the short term, and by product demand that is highly variable and subject to significant downturns that may adversely affect our business, results of operations, and financial condition." (Intel 2007)

As pointed out by the above quote from the 2006 Intel Annual Report, capturing equipment reuse opportunities may significantly impact bottom line indicators. Especially three favorable factors make this reuse program attractive and necessary: the expensive cost of capital equipment, the rapid product and technology "clockspeed" (Fine 1998, p. 6-7 & 239), and strategic move to fast-growing markets.

With an asset turnover ratio (i.e. the amount of sales generated for every dollar's worth of assets) of 0.75, Intel®'s ratio is clearly in the lower range compared with other types of industry (see Figure 2-1). This fact is an indication that Intel® should utilize its assets in a more efficient manner and capital equipment may offer greater leverage. Indeed, in 2006, the net book value of Intel® plant, property and equipment (original cost minus depreciation and amortization) accounted for one third of its total assets (Intel 2007). Moreover, for a leading-edge factory, cost of capital equipment generally ranges between \$2 and \$3 billion (Jefferson Jun. 2005), which represents about 75 to 80 percent of the cost of building an integrated circuit plant (Clendenin 2007). Finally, since the cost of leading-edge equipment is only going higher, the need to support efforts in reusing equipment will result in not only higher return for every dollar spent on capital but also cost avoidance in purchasing new equipment.

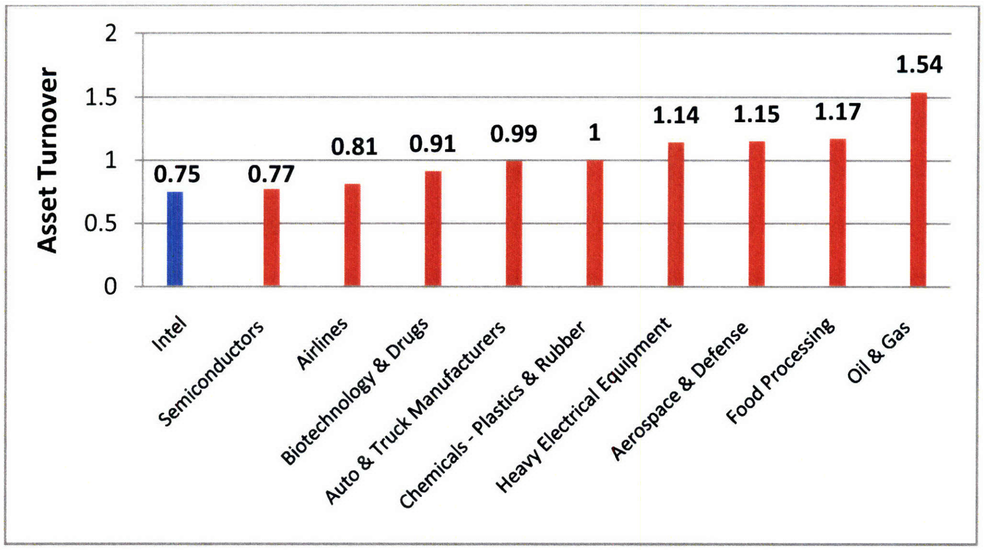

Figure 2-1: Turnover Ratio by Industry – (Reuters 2007)

In 1965, Gordon Moore predicted that the number of transistors on a chip would double every two years. This law, called Moore's Law, has been verified since the introduction of the first Intel® processor, the Intel® 4004 processor, in 1971 (Intel 2007). Not only has the number of transistors increased but also the manufacturing technology dimensions (i.e. the sizes of these transistors) have decreased at an exponential rate (see appendix A). This relentless move toward miniaturization has forced Intel® to constantly innovate and modify its manufacturing capability. For instance, between 1991 and 1996, at a time where reusing tools was not part of Intel® culture, Intel® purchased \$13 billion in new equipment (Weisberg and Rigoni 1999). Given that in 1997, the gross book value of Intel® plant, property and equipment (i.e. original price paid without depreciation deduction) was \$18 billion, we can estimate that during this period, Intel® renewed approximately 10 percent of its equipment per year just because of technology evolution. Miniaturization is one solution to increase the number of processors produced per wafer. Another way is to increase the wafer size. In 1978, Intel® used 51mm wafers to produce its Intel® 8086 processor. Since then, the wafer size increased at approximately a rate of 50 mm every ten years. In 2001, Intel® started producing with 300mm wafers, and expects to reach 450 mm in 2012 and even 675 mm in 2021 (Kramer 2006). By the end of 2008, most Intel® Fabs will be converted to 300 mm. Even if reusing the same capital equipment over different technologies is challenging, Intel® technology group always tries to do so by the adjunction of parts and upgrades, called conversion kits.

Finally, Intel® is progressively moving its production capacity to foreign countries because of increasing pressure on price from the personnal computer industry (Clendenin 2007) and potential for future growth (Intel 2007). In 1993, Intel® moved to Ireland with the construction of Fab10. Over the ten first years, low corporate taxes and other incentives saved Intel® approximately $1 billion (Friedman 2006, p. 408). In 1999, Fab18 opened in Israel in part because the state of Israel paid $600 million in grants, financing of plant infrastructure, and tax rebates (Thurow 2003, p. 282). Moreover, in March 2007, Intel® announced plans to build and operate in 2010 a $2.5 billion plant in China, Fab68 (Barboza 2007). In this case, tax rebates and incentives account for $1 billion. However, building a plant in foreign countries such as China goes with some compromises. Weak enforcement of intellectual property rights and potential military applications of Intel® products forced Intel® to commit to the United States government that Fab68 will use technology at least two generations behind the one used in the United States. Thus, in 2010, China will use the 90-nm process technology introduced in the United States in 2002. At this time, Intel® is expected to produce in the United States at 32-nm or even 22-nm (Clendenin 2007). On one hand, one may consider that such restriction may penalize Intel®, but on the other, this constraint offers a great opportunity to reuse process equipment from End-Of-Life (EOL) plants; approximately half of the equipment used in China will come from United States plants which will have moved to another technology.

To conclude, because of high cost of capital, fast change in technology and strategic move to fast-growing markets, the need for an aggressive and efficient tool reuse program has become more and more important. Not only the financial impact may be significant, but also Intel can see benefits in process development, equipment reliability and training. "In the absence of equipment reuse, each new technology would require manufacturing and process engineers to relearn a tremendous amount of additional information" (Jefferson Jun. 2005). Moreover, after the adoption of the Copy EXACTLY! factory strategy, the standardization of process configuration, equipment identification, performance metrics and definition of equipment capacity across factories has permitted the development of such a reuse program (Haney and Canter 2005). Thus, by launching in 1998 an aggressive reuse strategy, Intel® realized in excess of $6 billion of net capital investment avoidance over the first seven years of its existence (Jefferson Jun. 2005).

2.2 Tool Reuse Program and Allocation Process

From a high level prospective, a tool reuse program may be decomposed into four process steps as represented in Figure 2-2 (Weisberg and Rigoni 1999). The two first steps will be described in detail in the following two sections. A schematic representation of these steps is included in appendix B. The two remaining steps are part of the 6D Program scope and are presented in a separate chapter.

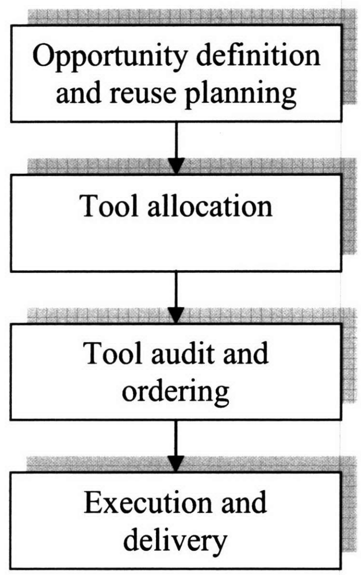

Figure 2-2: Tool reuse process flow

2.2.1 Opportunity definition and reuse planning

The first step of any tool reuse program must determine whether a specific tool may be reused and under which conditions. If the tool is from the same basic model as a tool in a new technology, it can be easily reused with or without additional parts and upgrades (conversion kits). However, technical feasibility analyses have to be done on a case-by-case basis by Intel® Technology Development (TD) specialists. Generally, for a current "N" generation technology, the only available tools are from the "N-2" generation ramp down because the "N-1" generation is at its production peak (Jefferson Jun. 2005). In addition, the current move from 200 mm to 300 mm has generated physical space constraints that prevent reusing many tools. In either case, the technical performance information and the list of conversion kits are summarized in a system called Model of Record (MOR).

By and large, the cost of reusing a specific tool is much lower than the price of a new tool. However, in cases where the cost of the conversation kits exceeds thirty percent of the cost of a new tool, the finance department verifies whether the reuse decision makes economical sense with the calculation of a return of investment[1] (ROI). (Bodmer 2007)

2.2.2 Tool allocation

This Section corresponds to the second step of Figure 2-2. First, we describe the process flow as it is done at Intel®. A schematic view can be seen in Appendix B. Then, we describe the retirement process and the four possible outcomes for a tool: reuse, resale, part harvesting, donation, or scrap. Finally, a theoretical tool is derived to support decision between harvesting and selling a tool.

2.2.2.1 Allocation of reused tools

Tool allocation is a complex and large problem involving thousands of tools worth several billion dollars, and subject to many constraints including balancing the capacity load across the virtual factory, meeting technology requirements, matching expected releasing and receiving dates, and minimizing global cost.

At Intel®, several systems are involved during this process. Every quarter, depending on the long term demand (generally two years), the Long Range Planning (LRP) system determines which factories will have excess or will require additional capacity. At the same time, it forecasts when excess tools will be out of production (CFD: Capacity Free Date) and when new tools will be required to meet production targets (CND: Capacity Need Date). This forecast is then sent to a project management software tool, P3E (Primavera), which calculates the availability date of the tool (Request Dock Date). Finally, an optimizer, Strategic Tool Allocation Resource System (SuperSTARS), finds matches between Request Dock Date and Capacity Need Date for each tool type. This whole process of designation and allocation of a tool is called the Multi-Factory Push-Pull (MFPP) process and is presented in appendix B.

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[1] Actually, in this case, the term ROI is used improperly. Instead of calculating an ROI, expressed in percentage, the finance department uses a net present value (NPV) with an annual discount rate of 15%.

As previously mentioned, SuperSTARS is an application used to optimize the allocation of excess inventory and to provide a standard methodology for allocating tools across Intel®. From a high level prospective, it is a linear programming model that determines the allocation that minimizes global cost of reuse (Ali, et al. 2005). For each possible allocation, penalty cost based on costs of conversion kits, transportation, and demolition and installation activities, is assigned to each assignment.

The problem can be mathematically expressed as:

$$\min \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$$

$$\text{subject to the constraints: } \begin{cases} \sum_{j=1}^{n} x_{ij} = 1 \text{(supply constraints)} \\ \sum_{i=1}^{m} x_{ij} = 1 \text{ (demand constraints)} \\ x_{ij} \text{ binomial} \end{cases}$$

with x_{ij} the decision variable representing the assignment from i to j, and c_{ij}, the associated cost.

Much emphasis is put to maximize reuse but in some cases it is not possible. The three main causes are:

- Cost: ROI is not positive for reuse tool (conversion kit cost, installation, demolition and warranty cost).
- Technical: The tool cannot be converted or may generate technical issues.
- Timing: The Request Dock Date is not early enough to meet the Capacity Need Date.

2.2.2.2 The retirement process

If the tool cannot be reused, it enters what is called the retirement process. At this stage the tool may have four different destinations (ranked by order of priority):

1. Resale: Intel® Resale Corporation (IRC) is the organization dedicated to the sale of Intel® surplus assets[1]. Indeed Intel® can be held liable for selling a tool containing hazardous material. By using a dedicated organization, Intel® can mitigate tax and legal risks. When IRC receives the list of retired tools, they assign for each tool a priority from P1 to P5 based on its fair market value, its percentage of return (ratio of the fair market value over the original price), and its market demand (see matrix in appendix B). This priority is used to help define the retirement disposition of the tool and constitutes a signal to the Fabs to schedule demolition activities.

2. Donation: For educational or research purpose, universities ask Intel® for unused tools. These demands are generally often satisfied.

3. Harvest: The harvest program is a way to maximize value extraction from a retired tool by taking its useful parts. The actual policy is to avoid harvesting consumables (gaskets, filters), and parts which have a value inferior to one hundred dollars, historical break or known EHS issues. Finally, part harvesting is critical for End-Of-Life (EOL) tools since many of these parts can no longer be purchased. In this case, harvest has priority over resale and donation. When the decision is to harvest the tool, only the useful parts are kept and the remainder of the tool discarded. This offers many advantages: a gain of inventory space, a faster response when the part is needed, and the possibility to send the part to other Intel® Fabs.

4. Scrap: As a last resort, the tool is dismantled and discarded.

Generally the decision does not draw much discussion. Indeed, if a tool has a high market value and the demand is high, it is very improbable that it will be required for harvest. On the

[1] Intel Capital (ICAP) is also authorized to sell Intel® assets but historically the majority of resale tools have been done by IRC.

contrary, if a tool is EOL, it is generally synonymous with outdated technology, low demand and low market value. However, in some rare cases, an ROI is calculated to compare resale and harvest solutions. For resale, the fair market value is discounted for one year, and only incremental costs (i.e. shipping fixtures and transportation) are included. For harvest, the estimated value of the tool is based on a Bill of Material (BOM) which sums the values of the useable parts (or not already in inventory without demand), at the price they would be bought from suppliers. This value is not discounted.

One can look at the harvest-sell option in terms of the value of the parts in inventory. The literatures suggest comparable approaches for slow moving inventory. For example, as pointed out by Rosenfield, "[the] real question in the treatment of [slow-moving or obsolete] inventory is not necessarily whether to salvage or dispose of an entire [tool], but what number of each units to keep" (Rosenfield 1989). Indeed, each part constituting the tool is worth a value depending on the number already in inventory which is linked to the expected date it will be used. Therefore, to estimate the value of a tool that may be harvested, we have to discount the price of each individual part by the expected time it will be kept in inventory. The main difficulty in determining a formula lays in the fact that each part has its own expected release date, based on a stochastic demand and the already existing inventory.

2.2.2.3 Proposed improvement

The following Equation 2-1(see demonstration in appendix D) captures all the constraints previously mentioned to evaluate whether a tool should be harvested or sold. If the inequality is true, then the tool has to be harvested. If not, the tool has to be sold. Indeed, the left side of the equation if the value of the tool if sold (discounted market value minus the cost of selling the tool). The right side of the equation represents the value of the tool if harvested (sum of the discounted value of the individual parts minus the cost of harvesting).

$$\sum_{i=1}^{N}\left[\left(A_i+\frac{r_i}{\delta}\right)\left(\frac{\lambda_i}{\lambda_i+\delta}\right)^{I_i+1}-\frac{r_i}{\delta}\right]^{+}-C_h \geq \frac{V\mu}{\delta+\mu}-C_s$$

Equation 2-1: Condition to harvest a tool

With:

μ : Average number of tools expected to be sold by unit of time. (unit: 1/year)

δ : Continuously compounded discount rate = 14%. (unit: 1/year)

λ_i : Average number of parts of type *i* demanded by unit of time. (unit: 1/year)

A_i : Value of part of type *i*. (unit: \$)

C_h : Total incremental cost of harvesting the tool. (unit: \$)

C_s : Total incremental cost of selling the tool (crating, shipping fixtures…). (unit: \$)

I_i : Number of parts of type *i* already in inventory.

N : Number of part types that can be harvested for the tool.

r_i : Cost per unit of time of space and other non-capital holding costs for the part of type *i*. (unit: \$/year)

V : Sale value of the tool. (unit: \$)

The notation $[x]^+$ means: $[x]^+ = Max[0; x]$.

As a numerical example, we take the following case:

- Option 1: Sell the tool

The considered tool can be sold for one million dollars. To prepare the tool specifically for resale (packaging, crating, transportation, etc.), it costs an incremental one hundred thousand dollars. Finally, Intel® Resale Corporation expects selling between one and two tools during the next year. These values are summarized as follow:

Fair market value of the tool: V = \$1,000,000

Expected number of tools to be sold per year: μ = 1.5

Incremental cost of selling the tool: C_s = \$100,000

- Option 2: Harvest the tool

The same tool can also be harvested. Four different parts are worthwhile to consider because their market value is high (superior to one hundred thousand dollars) and the demand is significant. Additional informational in this scenario is summarized in Table 2-1. Finally, it costs an additional fifteen thousand dollars to take apart these pieces.

Cost of harvesting the tool: C_h = \$15,000

Part type	Number per tool	Inventory	Unit price	Demand per year	Unit cost of storage per year
A	1	1	\$ 100,000	0.5	\$ 100
B	1	3	\$ 100,000	1	\$ 150
C	1	1	\$ 500,000	0.3	\$ 500
D	2	4	\$ 200,000	2	\$ 250

Table 2-1: Data for harvesting the tool

At a first glance it seems that the tool should be harvested. Indeed, the total value of the tool if harvested is worth \$1.1 million with a cost of harvesting of \$15k, compared with a fair market value of \$1 million and at a cost of \$100k to prepare it. However, a second look shows that it may not be so obvious. Indeed, part C has a high value but is not often replaced and some of the parts with a higher demand (B and D) are already in high quantity. By using the formula previously mentioned we find that the harvested tool is worth \$609,812 (Table 2-2) compared with a value if sold of \$814,634[1]. Therefore the tool should be sold. Note that, since the tool contains two parts D, each part D has to be calculated separately by incrementing by one the existing inventory for each additional part.

[1] $\frac{1.5}{1.5+0.14} * 1{,}000{,}000 - 100{,}000 = 814{,}634$

Part type	Discounted value	
A	$	60,757
B	$	58,771
C	$	230,527
D1	$	142,085
D2	$	132,673
Total	$	624,812
- Cost of harvesting	$	(15,000)
Grand total	**$**	**609,812**

Table 2-2: Results of the option "Harvest the tool"

To conclude, by taking into account the stochastic character of the demand, the diminishing return of additional parts in inventory and the cost of keeping these parts on stock, Equation 2-1 may be a valuable tool for the retirement process. However, availability of reliable data still remains. Indeed, the same phenomena that Gan describes in his thesis (Gan 2007) about knowledge management in the 6D Program happen in this case too. Existing information may only be available in different systems, duplicated data not coherent between multiple systems, or information may simply be missing.

2.3 The 6D Program

As defined by the framework in Figure 2-2, the last two steps of a tool reuse process are "tool audit and ordering" and "execution and delivery," which encompass the validation that the tool can in fact be reused (no major configuration issues or process problem), and the demolition, transfer and installation of the tool.

Prior to 2004, no formal process was in place to ensure that assets were transferred in a safe and timely manner. This resulted in major safety and reliability incidents that pushed the creation of the 6D Program at the end of 2004. Initially, this program contained only activities performed by the releasing site (decontamination, decommission and demolition). It is only at the beginning of 2005, that the scope was expanded to delivery and deployment. In its present form, the 6D Program is comprised of seven steps: Pre Demo activities, Decontamination, Decommission, Demolition, Demolition of Utilities, Delivery and Deployment. These steps will be studied in detail in section 2.3.2.

Two previous LFM internships studied the 6D process. The first one (Silber 2006) resulted in recommendations to improve crating reuse and warehouse inventory management with a BAP RFID system. The second internship (Gan 2007) showed gaps and opportunities in knowledge management.

2.3.1 Mission and Vision Statement

The actual mission statement of the 6D Program is:

" Preserve Intel®'s assets during transfer, from decontamination through deployment, using safe, effective procedures and business processes."

And the vision statement:

"100% on time tool transfer with zero severity 1 incident[1]."

Based on a survey made in October 2007 (appendix C), this mission and vision reflect the three main objectives of a demolition of a tool: safety, reliability of the tool and on-time delivery.

2.3.2 6D Process Overview

This Section describes the seven steps of the 6D Process: pre Demo activities, Decontamination, Decommission, Demolition, Demolition of Utilities, Delivery and Deployment. A schematic view of the process is presented in Figure 2-3.

---

[1] Severity definition:

1. High severity: Capital loss > $200k / Missed ramp-up / Accident or injury.
2. Medium severity: Capital loss between $20k and $200k / Caused schedule compression / Unauthorized cannibalization.
3. Low severity: Capital loss < $20k / Procedural or price issue / No safety issue

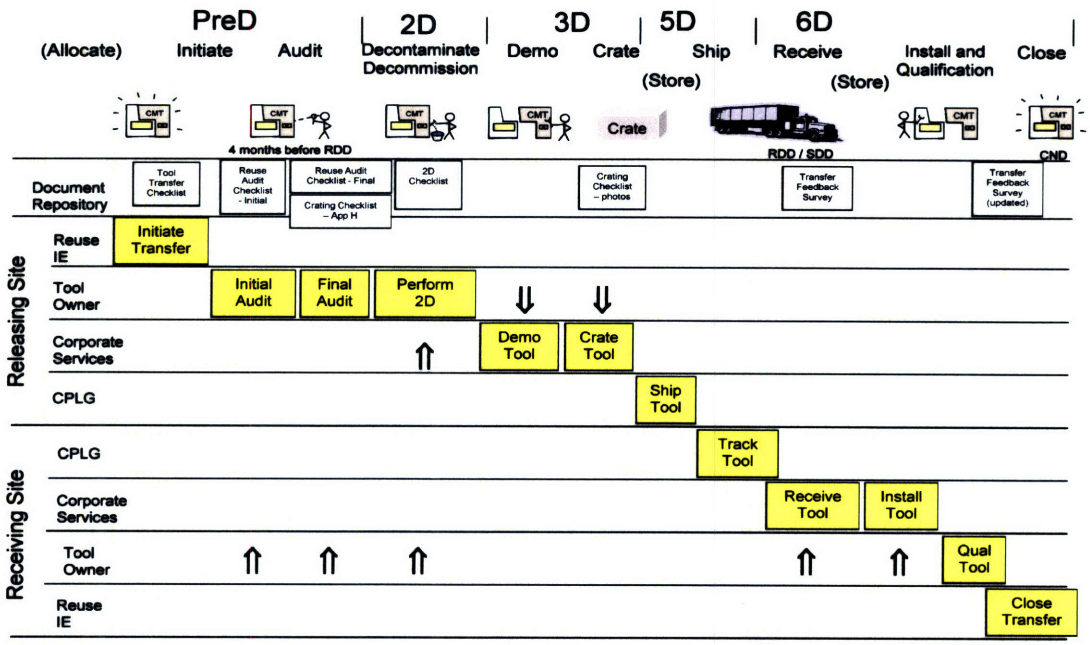

Figure 2-3: 6D Process Flow

2.3.2.1 Pre Demo activities

Before starting the activities of demolition of a tool, a series of tasks has to be performed. This phase is called Pre Demo. Its purpose is to document tool condition and performance, as well as to plan the activities to demolish the tool.

Several months before the planned end of production (Capacity Free Date - CFD), the Project Lead initiates the project and determines scope, schedule, budget, resources, and the expected condition of the tool. An initial audit (Tool Reuse Physical Audit) is conducted to assess the condition and functionality of the tool, the accuracy of the Bill of Material (BOM), and to identify any missing parts or critical long lead items that will be required for re-installation. Moreover, all critical tool performance data, such as utilization rate or quality results, have to be entered into a system called TRANS (Tool Reuse Audit Network System). This data will be used by the receiving site as a basis to restart the tool.

Once this initial audit is finished, the assigned Tool Owner (TO) receives the tool Installation Package from the Design Group. This document includes configuration of the tool, isometrics of the lines, electrical connection, etc. Generally this package is not accurate.

Indeed, the Sustaining Group may have improved or customized the tool without notifying the Design Group. Also, cost-benefit analyses showed that maintaining these drawings up-to-date was not justified. Therefore, during an activity called "Red Lines," the TO verifies construction drawing accuracy by "walking the tool." Even if this activity may be tedious, it offers two main advantages: an opportunity for the TO to learn about tool configuration and it provides an accurate basis for contracts with external groups that participate in the demolition.

Then, based on his findings, the TO creates a 2D Checklist. This tool type specific document describes the sequence of tasks to be performed to safely and efficiently decontaminate and decommission the tool. In many cases there are existing and proven 2D Checklists and the TO will use these checklists as a baseline.

Finally, after the CFD and just prior to the start of the 6D process, a Tool Pre Demo Audit is conducted to ensure that the tool is fully functional.

2.3.2.2 1D: Decontamination

The first step of the 6D process is called Decontamination. It consists in purging and flushing all gases, chemicals, and liquids, as well as cleaning the tool of oils, wafer shards, and residues. Therefore the expected result is a clean and dry tool with consumables removed. Failing during this step may result in corrosion issues if the tool has to be stored for a long period, as well as environmental or personal safety concerns when the tool is uncrated. Indeed, the semiconductor fabrication process uses many toxic materials. These include poisonous elemental dopants (e.g., arsenic, boron, antinomy, or phosphorus), poisonous compounds (e.g., arsine, phosphine, or silane) or highly reactive liquids (e.g., hydrogen peroxide, fuming nitric acid, sulfuric acid, or hydrofluoric acid) (Wikipedia 2007). To be considered safe by the Environmental Health and Safety (EHS) Group, the pH must range between 6 and 8.

However, leaving a perfectly clean tool is not always possible. For instance, wet benches[1] typically contain twenty five different types of chemicals, and are made of polypropylene

[1] A fully automatic process tool used to carry out wet cleaning and etching (process of transferring the pattern to the wafer) operations. This tool commonly includes several tanks each containing either cleaning/etching solution or de-ionized rinsing water in which wafers are immersed in predetermined rinsing sequence.

which may absorb these chemicals under certain circumstances. Therefore, even with careful wash and rinse with water, may still retain chemicals that the polypropylene will desorb one or two weeks later. In 2005, Intel® reported eight (out of twenty seven) incidents related to this issue.

Finally, since the tool cannot properly decontaminate without some decommission steps being performed, these two steps are inextricably linked and are frequently referred as "2D" (see Figure 2-3).

2.3.2.3 2D: Decommission

Tool Decommission consists of powering down the equipment, disconnecting the tool from automation systems and utilities (except exhaust, drains and electrical), and adding shipping fixtures to prevent damage during shipment.

In addition, all Intel® proprietary information must be removed per Intel® Information Security Policies. In many cases, this step is obvious but sometimes this "proprietary information" is inherently part of the tool. For instance, the hard drive containing the operating system may have been programmed by Intel® Technology Development (TD) for the specific application of the tool. Hence, selling the tool with this hard drive may divulge some proprietary information, but without it, the tool is unusable.

Finally, once tool and sub-Fab equipment decontamination and decommissioning are completed per the 2D Checklists, a walkthrough, called Demo Safety Level 1 (DSL1), is carried out to ensure that the tool is ready to begin the Demolition (3D) process.

Depending of the tool type, the duration of the two first D's ranges between one and twenty days.

2.3.2.4 3D: Demolition

The first phase of Tool Demolition consists of disconnecting the tool exhaust, drains, and electrical connections. At this point another walkthrough, called Demo Safety Level 2 (DSL2 - Tool Ready to Move) is conducted to ensure that the tool is ready to move and all interconnect cables required for tool install have been pulled. Post DSL2, the tool is physically "ready to move," but will require move preparations.

Indeed, moving a tool out of the factory exposes it to a non-clean room and non climate controlled environment. In order to protect the tool from moisture and condensation and ensure a humidity level below forty percent, the tool is wrapped in an airtight seal with desiccants. Then, the tool is padded to prevent physical trauma and individual tool components are protected in crates. Packaging and crating requirements vary based on mode of transportation, destination, and eventually duration and condition of storage. For instance, some National Plant Protection Organizations require debarked or bark-free wood as a requirement for import, and China has special requirements in term of documentation attached to the tool.

Typically, the duration of the demolition step ranges between two and twenty days with one day for moving out and one day for crating.

2.3.2.5 4D: Demolition of Utilities

Demolition of Utilities is the Decommission, Decontamination, and System Demolition of Base Build / Process Specific Support Systems (PSSS). The scope generally includes mains, laterals, and other utilities to facilitate a base build project for the future. Demolition is completed on a selected basis depending on the reusability of the system and in order to leave the area in a safe and reusable condition.

2.3.2.6 5D: Delivery

The Delivery step consists of the movement of capital equipment from Intel® dock to its final destination. The final destination can be reuse by another Intel® Fab, resale by IRC, donation to educational institutions, harvest or scrap. The tool can be either directly delivered to its final destination or temporary stored in an Intel® controlled warehouse or in that of a third party logistics (3PL) provider.

Since the tool is subject to a number of stresses that would never be present during normal use, damage may occur in shipment. Another known issue is cannibalization in the warehouse.

2.3.2.7 6D: Deployment

The last step of the 6D program is Deployment of the complete capital equipment at its reuse destination. It includes uncrating, installing and qualifying the tool.

Each time a tool is deployed to another Intel® Fab, it should be a learning experience for all parties involved in the 6D Program. This is done formally through the Receiving Site Certification. Since this closed loop process was put in place, the 6D Working Group has expressed concerns about the percentage of receiving sites completing certification: less than fifty percent is filled and generally it is done only when receiving Fabs express major concerns when reusing the tool. This low response rate is therefore a major roadblock in improving the whole 6D process.

However a successful reuse of a tool is very important for Intel®. For instance, if the tool is expected during the ramp-up of a production line, failing in deploying the tool may have detrimental consequences for Intel®. Not only may it have economical, but also long-term commercial consequences, which are hard to evaluate. The main components for a successful transfer are obviously a complete and functional tool, as well as a good communication between the releasing and the receiving sites. Therefore the involvement of the receiving site at the early stage of the process to communicate its expectation, and accurate and relevant historical data from the releasing site are fundamental for a flawless transfer of the tool.

3 Leadership Challenges: Global Team vs. Local Priorities

This Chapter is about leadership challenges faced by the 6D Working Group to influence and coordinate standardization of the procedures. First, we analyze the organization through three lenses: strategic design lens, political lens and cultural lens (Carroll 2001). Based on this analysis, we explore the difference between compliance and accountability of the sites, and conclude that the program may lack figures dedicated to lead accountability of the execution of the processes. Finally, using a game theory analysis, we advocate that the lack of accountability of the sites, revealed through cannibalization of tools, is a result of the actual incentive policy and then a revision of this policy is proposed.

3.1 Three Lens analysis

The following sections describe the enterprise using the Three Lenses approach taught at the MIT – Sloan School of Management. Under this design, the organization can be viewed from three perspectives: the strategic, the political and the cultural.

3.1.1 Strategic Design Challenges

Demolishing and transferring a tool from one site to another cannot be done without the active participation and the coordination of many different groups of people: Engineering, FSM (Fab Sort Manufacturing), CSC (Corporate Services Construction), EHS (Environmental Health and Safety), CPLG (Customer Fulfillment, Planning and Logistics Group), Finance, and others. As we can see, these groups are sorted by function. Indeed, as a manufacturing company, Intel® justifies this type of organization because often specialization leads to economy of scale, efficiency, and innovation.

However, drawbacks can appear when integration between groups is required. Indeed, the company may face a situation where each group has its own information system and even some information may be inconsistent from one system to another. For instance, it may be surprising to see that each tool has four different denominations: an SAP number, an asset number, an E-Tag and a Tool Id. Another drawback of this lack of integration may be some gray areas in the transmission of tasks. Indeed, the Decontamination and Decommission steps are performed by FSM while the Demolition is executed by CSC. As pointed by these two examples, in order to execute a tool transfer, communication channels have to be set up not only between sites but also at every level of the organization.

Figure 3-1 presents a simplified view of the organization in place to manage the transfer of tools. From a strategic point of view, the 6D Management Over-site Committee (MOC), composed of Fab managers, and the 6D Core Team specify the objectives, and validate policies and plans. At a tactical level, the 6D WG, composed of the 6D Core Team and the 6D SPoC of each plant, design the systems and procedures to achieve these objectives and spread them through individual sites. Finally, at a operational level, Tool Owners (TO) are in charge of following these procedures to demolish or reinstall a tool. Communication between sites is carried out by Tool Transfer Coordinators (TTC) and Reuse Coordinators. Their mission is to facilitate the transfer of tool within the Virtual Factory. Also, if an issue arises during a tool movement, they are in charge of driving its resolution.

However, at the individual level, some parts of this structure differ from site to site. For instance, specific work can be performed by Blue Badges (Intel® employees) in one site while the same step will be completed by Green Badges (contractors) in another. These differences impede standardization and are a clear barrier in the 6D WG efforts to coordinate the processes used and foster continuous improvement. This leads to a situation where only general guidelines and checkpoints are proposed and applied or not, depending on the site organizational structure.

Indeed, the 6D WG is what we call a Virtual Team, a group of individuals geographically dispersed with the mission to promote a global optimum for the corporation per opposition to local optima per factory. For the 6D Program, the 6D Core Team located in New Mexico transmits information to the Fabs through the SPoC who is in charge of training local teams and insuring that the right processes are followed. The role of the SPoC is crucial in the 6D Program success because he is the only one who can ensure that local actions are aligned with global objectives. As noted by Klein and Barrett, this mission is not easy because they "must develop a perspective that allows them to see the work for the team as part of a global strategy, even if it means a personal struggle with the fact that what is good for the entire organization might not benefit their home location." (Klein and Barrett 2001)

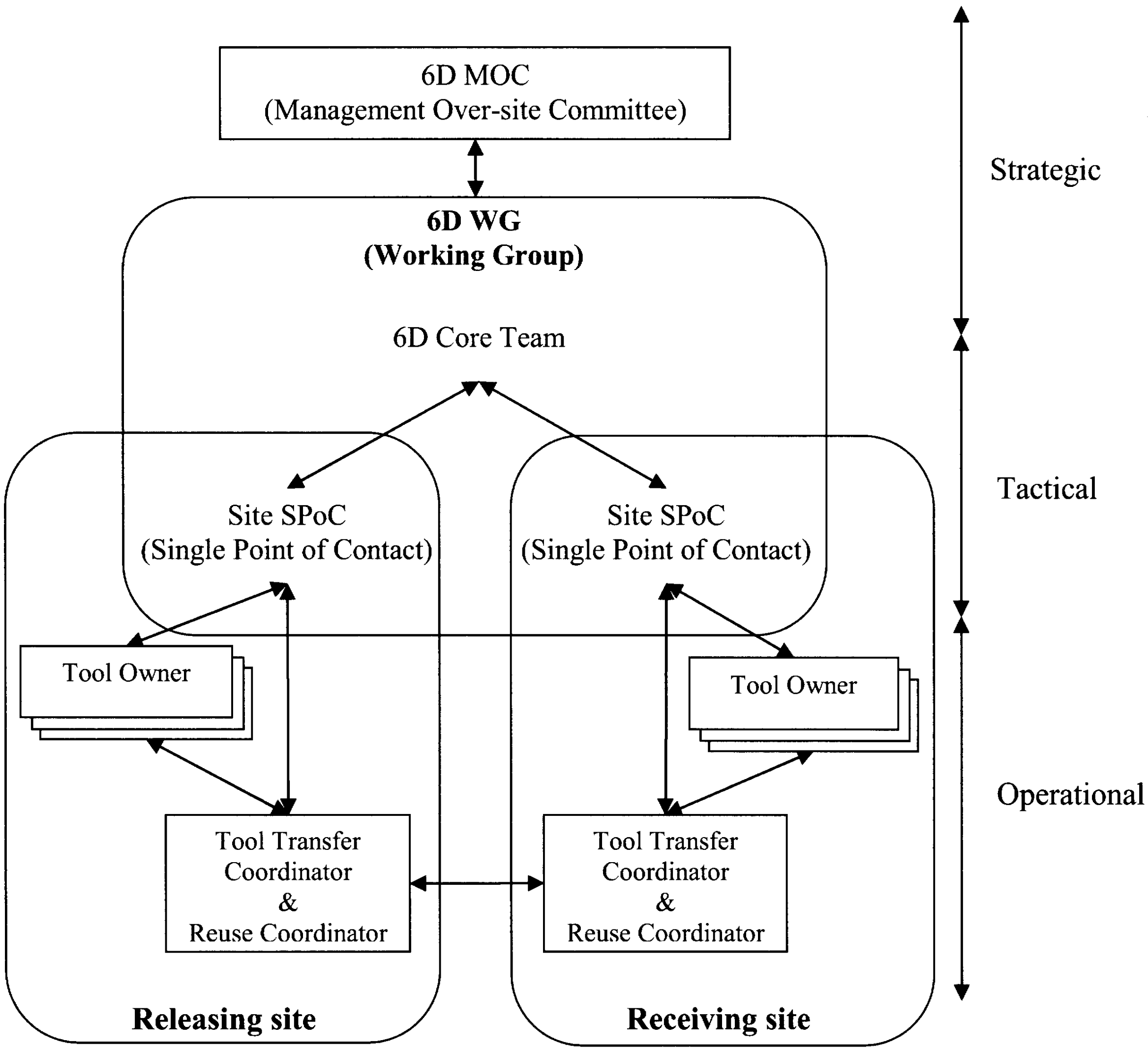

Figure 3-1: Simplified organizational structure

3.1.2 Political Challenges

In order to align sites with these global objectives, the 6D SPoC needs to be a senior person with wide and lateral influences and connections to many organizations. Through interviews with most of the 6D SPoC, it seems clear that this political influence is real in sites where demolition activities are significant. For instance, in New Mexico or Colorado, a whole part of the factory was shut down and hundreds of tools had to be transferred or sold. In these cases, the 6D SPoC had direct contacts with the Factory Manager. However, when only a few tools are demolished, more junior and inexperienced people are in charge. This leads to less compliance to the processes.

Another challenge in reaching a global agreement is the fact that people are mainly judged for local improvements. As stated by Klein and Barrett, "if the corporation has created competition between sites for future business, local sites will be unwilling to share their knowledge and practices" (Klein and Barrett 2001). Not only does competition exists between sites but also between groups. To the individual level, incentives are aligned with local and even group objectives, not global objectives. This political power exerted by direct management is a real barrier to overcome since the 6D WG has no hierarchical authority.

Finally, the main goal of the 6D WG is to promote process sharing and collaboration between sites. However, "the application of best practices around team processes and collaborative technologies are critical but insufficient if the natural tension between global and local priorities is ignored" (Klein and Barrett 2001). For instance, in some cases, demolition of tools is linked with end of activities at a particular fab site. Therefore, it is very hard to motivate people to share best practices or improve the existing ones since it would result in earlier lay off.

In the previous two parts, we saw that significant differences in organizational structures, incentives and objectives impede alignments and commitments to the 6D Program. Moreover, in several instances, corporate and local objectives are in opposition. However, in the 90's, Intel® implemented Copy EXACTLY! with the aim to duplicate and standardize the same equipment and methodologies at all sites. The next section analyzes whether this Copy EXACTLY! culture may influence and help the 6D WG in promoting standardization and shared learning in order to reduce duplication of efforts between sites that demolish the same type of tools.

3.1.3 Cultural Challenges

Before Copy EXACTLY!, Intel®'s manufacturing Fabs were allowed to modify new process technologies. However, variations between sites resulted in significant differences in production yield and longer technology transfer times. In order to minimize these risks, Fabs started copying equipment and processes used in development sites. Once the same yields were achieved, manufacturing Fabs were allowed to make individual improvements that had to be shared and implemented in other Fabs producing the same product.

As stated by the initiator of the Copy EXACTLY! program: "The Copy EXACTLY! Method is designed to match all factors that impact the process or how it is run. Other systems might benefit from matching, but time and money should not be wasted on matching factors that have no impact on the overall process" (Donald 1998). In other words, Copy EXACTLY! focuses on standardizing equipments, process technology and parameters, and methods. By doing so, Intel® can quickly reduce qualification time (Beckman and Rosenfield 2008, p. 68-70). Copy EXACTLY! fosters standardization of processes influencing production quality and yield. Therefore, tool demolition procedures, that obviously do not directly contribute to production, do not enter into the category of Copy EXACTLY!. Moreover, the word "exactly" is capitalized, underlined and with an exclamation point because the paradigm change was actually hard to put in place. It required a push from top management to counter natural tendencies of the organization. "The difficulties in implementing this new philosophy and system are not to be underestimated. [...] Engineers are trained and rewarded for doing improvement projects, and production re-qualification affords them such an opportunity. The natural tendency is thus to use the new start-up as an opportunity to implement improvements." (Donald 1998)

We can see that the root cause of Intel®'s difficulties to implement large scale programs may lie in its engineering culture: analytical thinking can be seen in every Power Point presentation, every layer of management is filled with engineers, and the influence of the Technology Group mainly composed of PhDs, is significant on the whole corporation. It creates a technocratic culture based on data and rational thinking. However, "the strong focus on data in technocratic firms [...] can sometimes hinder the introduction of such concepts as organizational learning, since these are less easily quantifiable." (Klein 2004, pp. 78) Employees are rewarded for creating something new with measurable impact. Therefore, sustaining activities, such as tool reuse, are not highly valued.

Finally, competition between sites and technocratic culture have fostered a "not invented here" culture. This culture is clearly visible with the extensive use of acronyms which makes Intel® not only a unique company because people are using their own language, but also creates barriers between sites because these acronyms may mean different things depending on the site.

At the beginning of this section, we saw that one of the main constraints in implementing a large scale improvement program for 6D was the lack of common organizational structure and misalignment of incentives. These gaps result in difficulties in spreading standardized processes and creating a learning organization. Finally, the experience given by the implementation of Copy EXACTLY! taught us that the root cause of these difficulties may lay in the "not invented here" syndrome fostered by an engineering driven culture and rewards for innovative and not sustainable activities.

3.2 From compliance to accountability

This section is about compliance and accountability. By compliance we mean "accordance with established guidelines or specifications" and by accountability, we mean "being liable for the consequences of failure to perform as expected."

3.2.1 The measure of compliance

Shortly after the creation of the 6D Program, the 6D MOC expressed the need for a measure of compliance to the 6D processes. The logic was that the more compliant the Fabs are, the more reliable the reused tools will be. In late 2005, the 6D Working Group started tracking site implementation of the 6D Program. Also, in January 2007, the 6D WG created a compliance score based on, for the releasing site, the number of 2D Checklists created and completed on time, and the use of the collaborative technology in place, and for the receiving site, the completion of the Tool Transfer Certification.

However, the results of a survey done in October 2007 (Appendix C – Question 2) showed major discrepancies in this compliance score. For instance, if we compare the self perception of the sites with their official compliance results (Figure 3-2), we note a very weak correlation (coefficient of determination is only 2.5%).

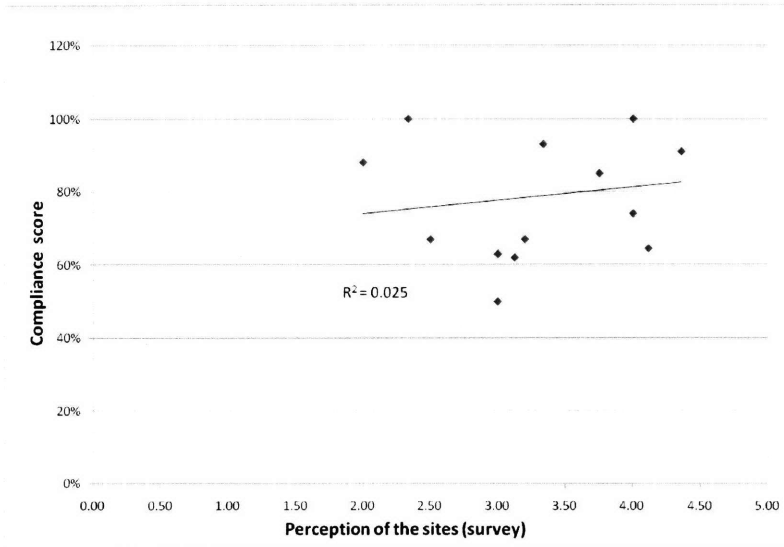

Figure 3-2: Correlation between the compliance score and the perception of the sites[1]

Additionally, the 6D Core Team was asked to provide their best estimate of what should be the real compliance score for each site. The result is shown in Figure 3-3. It is surprising to note that there is no correlation (even negative slope) between their perception and the compliance scores calculated and published every quarter. Finally, Figure 3-4 shows that there is an agreement between the sites and the 6D WG on what should be their level of compliance (positive correlation with a coefficient of determination of 19.5%).

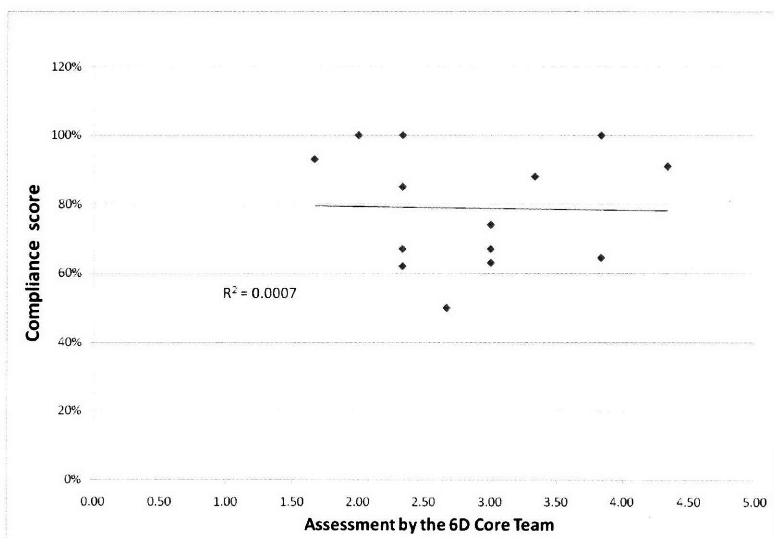

Figure 3-3: Correlation between the compliance score and the assessment of the 6D Core Team

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[1] Results based on 84 surveys for the 14 Fabs.

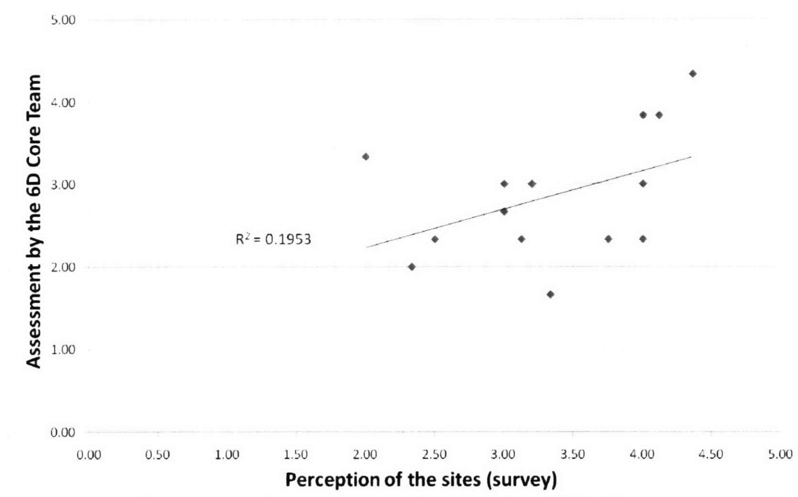


Figure 3-4: Correlation between the perception of the sites and the assessment of the 6D Core Team

The main conclusion is that the actual compliance scores do not match the definition shared by the 6D WG and the Fabs. Therefore, either the compliance score does not measure the main aspects of compliance or by compliance they may mean something different. Indeed, the next part will distinguish compliance (i.e. accordance with established guidelines or specifications) from accountability (i.e. being liable for the consequences of failure to perform as expected). In either case, presenting this kind of score and then ranking the Fabs accordingly to this metric may generate frustration and lack of understanding from both parts. Ultimately, it may be damaging for the 6D WG, as the 6D WG may lose a certain form of credibility.

3.2.2 The difference between compliance and accountability

In *A Reexamination of Autonomy in Light of New Manufacturing Practices* (Klein 1991), Klein states that decision making can occur in three different ways:

- Centralized: A manager or centralized figure makes the decision, or the decision is based on a rule or procedure.
- Independent: Responsibility is delegated to individuals to make independent decisions.
- Collaborative: The group comes to a decision.

On one hand, following a centralized decision ensures standardization and once tasks are standardized they can be improved. Indeed, by eliminating variations generated by autonomy, root causes of defects can be analyzed and solved. But to reach standardization, Fabs need to be compliant, i.e. acting in accordance with established guidelines and specifications.

On the other hand, autonomy has its virtue too. We mean by autonomy, "the degree to which the job provides substantial freedom, independence, and discretion to the individual in scheduling the work and in determining the procedures to be used in carrying it out" (Hackman and Oldham 1980). The same authors, Hackman and Oldham, emphasize the importance of this job dimension primarily because it is a basic component of human relations. On a more practical level, autonomy allows workers to shape process steps to the job that has to be done with an aim to be a more efficient and faster.

In order to measure the desired level of compliance / autonomy of the sites, the following question was asked to the sites (see appendix C – question 7): "How do you see the role of the 6D Working Group? (Rank the 2 best answers)" with the following propositions:

- Analyst – Measure performance / metrics to assess a Fab and determined room for improvement.
- Architect – Provide everything needed to manage the project: organizational structures, process, checklists...
- Consultant – Provide suggestions that can be applied or not, depending of the situation.
- Facilitator – Help in improving the processes by sharing best practices across Fabs.

Figure 3-5 summarizes the answers obtained. By distinguishing less experienced from experienced sites[1], we note that the more experienced the sites are, the more they want to be autonomous.

[1] The categories "less experienced sites" and "experienced sites" were defined with the help of the 6D WG. Each of these categories is composed of 7 Fabs and approximately the same number of answers (respectively 47 and 43). The aggregate result was obtained by assigning 2 to a first rank and 1 to a second rank.

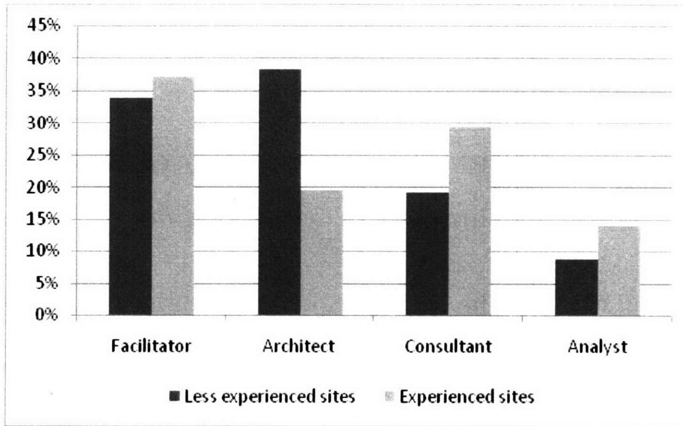


Figure 3-5: Influence of the maturity level of the sites on their view of the role of the 6D Group

This type of evolution is maybe natural or at least foreseeable for companies such as Intel®. Indeed, as mentioned in the previous part, the "not invented here" syndrome is still prevalent; Fabs want to take ownership of the projects, and because of organizational and tool specificities, they recognize that a one-fit-for-all solution may not apply. Moreover, by experimenting with new ways of doing their jobs, these sites may bring more to the 6D Program than Fabs which are "only" compliant.

3.2.3 The missing link

However, the 6D WG may not be in an appropriate position to lead process accountability. While it may be fairly easy to set metrics to drive compliance to certain activities, fostering accountability requires close supervision of the execution. Indeed, the 6D WG is the designer of the 6D processes, not the owner of execution. Actually, taking a process management approach (Hammer and Champy 1993), a process must contain the five following elements (Hammer 2007):

1. A well-defined *design*; otherwise, the people performing it will not know what to do or when.

2. The people who execute the process, the *performers*, must have appropriate skills and knowledge; otherwise they won't be able to implement the design.

3. The company must align *infrastructure*, such as information technologies or HR systems, to support the process.

4. The company must develop and use the right *metrics* to assess the performance of the process over time.

5. There has to be an *owner*, a senior executive who has the responsibility and authority to ensure that the process delivers results.

As mentioned, the 6D WG is the designer of the processes. To ensure that the people who execute the process are performers, the 6D WG goes from site to site to provide extensive training to every actor of a tool demolition and especially to the Tool Owner, who is generally an operator specialized in using the tool. To align the infrastructure with the process, the 6D WG created a web-based tool, TRANS. This tool standardizes the exchange of information between the releasing and the receiving sites. Finally, the group started to put in place metrics to follow compliance, safety issues, etc. (see Chapter 4.2 for more information and recommendations about metrics). Therefore out of these five elements recommended by Hammer, the 6D WG covers the first four. However, this group does not have the responsibility to ensure that the process deliver results. First, the 6D WG does not have hierarchical authority to implement the changes and is not physically on-site to follow the processes. Actually, this role is more or less attributed to the 6D SPoC. However, as seen in Section 3.1.2, the SPoC's influence is generally political, not hierarchical. Second, we also saw that, for a single tool, the process extends across functions and over two different sites. Therefore, only a senior executive may have the appropriate level of management to drive the 6D Processes. Without such a person, the process won't gain traction within the organization. On the other hand, this may not be practically realistic. The main reason being that tool transfer is only one process among many others and its relative importance is low compared with Intel®'s core competency of designing and producing semiconductors.

As a consequence, the traction has to come "naturally" through an appropriate set of incentives. Many famous business stories illustrate how inefficiencies can be seen when incentives are not aligned. For instance Hammer and Champy tell us the story of a company using multitiered distribution centers (Hammer and Champy 1993, p. 7). Before reaching customers, finishede goods are sent first to a central distribution center and then to a regional distribution center. They discovered that the process was taking eleven days because the regional distribution centers were rated on the amount of time they took to serve the customer, while the central distribution center was judged on inventory and labor costs, and inventory turns. The main conclusion is that locally these measures make sense while globally they have competitive goals.

3.2.4 How to build accountability? - Game theory analysis

We saw that Intel® Fabs are compared on local results and not cross-organization achievements. Therefore the lack of high level leadership combined with objective misalignments may explain why between ten and fifteen percent of the tools demolished are cannibalized. In this section, we use a game theory analysis to prove this assertion and propose a scheme to realign both the releasing and receiving sites.

3.2.4.1 Introduction to the game theory analysis

During a tool transfer event, releasing and receiving sites have several options in term of quality of communication and work:

1. The receiving site may or may not decide to cooperate before the demolition of a tool. Indeed, at the early stage of the process, the receiving site may visit the releasing site, audit the tool and learn about its technical specificities by analyzing data or talking with the releasing site Process Engineer. Even if a close cooperation at the early stage of the process may ultimately create more value than buying the same tool from a third party, uncertainties still remain whether or not the tool will arrive complete and functional and then offset the time and money invested in cooperating.

2. From the releasing site point of view, two options exist. On one hand, it may decide to execute a good demotion that can be defined as providing training to tool owners, creating and following procedures, and if necessary asking supplier specialists for some advice. On the other hand, the releasing site may decide to put only minimal effort in the demolition. In some cases, it can also cannibalize the tool.

3. Finally, the receiving site may put in place a formal structure to reinstall the tool. For instance, they may follow processes as defined by the 6D Working Group, and, if

necessary, bring on site the company which initially sold the tool to assist the installation process.

Two comments can be drawn from these three decisions. First, they are not independent. Indeed, the outcome intrinsically depends on the involvement of the releasing site: if the releasing site does a good demolition, the implication of the receiving site at the early stage of the process will substantially add value to the tool. However, if the releasing site cannibalizes the tool, whatever the implication of the receiving site before the demolition, the value of the tool will be the same. Secondly, these three decisions are not sequential; only the first decision is sequential to the second and third ones that are simultaneous and without cooperation. Indeed, before the demolition of the tool, the receiving site signals to the releasing site its level of involvement while its decision to formalize the reinstallation process is made independently and without knowing the releasing site decision.

To analyze the relation involving the releasing and the receiving sites, we use a game theory analysis. Indeed, as for the Prisoner's Dilemma problem, the question is whether it is in each party best interest to cooperate or not to deliver a specific tool in good condition.

Game theory was created in 1944 with the publication of the book *The Theory of Games and Economic Behavior* by a mathematician, John von Neumann, and an economist, Oskar Morgenstern, to model and analyze economic situations in which players, also called agents, have to define a strategy maximizing their gain, given the strategy of the other player (von Neumann and Morgenstern 1944). Applications of game theory can be found in many fields. For instance, in his book *Evolution and the Theory of Games,* John Maymard Smith applied game theory to animal behavior, population genetics and evolutionary biology (Smith 1982), William Poundstone in his book *Prisoner's Dilemma* describes applications in political science during the Cold War (Poundstone 1993), and in *Carnival Booth: An Algorithm for Defeating the Computer-Assisted Passenger Screening System (CAAPS)*, two MIT-graduate students, Samidh Chakrabarti and Aaron Strauss showed that terrorists could rather easily adapt their behavior to render CAAPS less effective than pure random selection of passengers for second-level screening (Chakrabarti and Strauss 2002).

A game theory analysis is useful when players face a conflict of interest. As defined by R. Duncan Luce and Howard Raiffa in *Games and Decisions* (Luce and Raiffa 1957, p. 1), a conflict of interest occurs when "an individual is in a situation from which one of several outcomes will result and with respect to which he has certain personal preferences. However, though he may have some control over the variables which determine the outcome, he does not have full control."

The analysis will be divided into three parts. First, the model used is presented as it was prior to June 2006. At that time, neither bill-back nor reward system was in place to foster behavior. In a second step, we analyze whether or not the bill-back process introduced in June 2006 improves the outcome. Since the conclusion of this second part is that the bill-back process does not significantly improve the final result, we will propose the application of a reward system (the receiving site pays the releasing site under certain conditions) that ultimately may achieve the best outcome for Intel®.

For confidentiality reasons and availability of the data, the costs and returns used in the following three parts are only estimates but within the typical range of a tool demolition. Even if the figures are not accurate, the main purpose of this exercise is to illustrate how game theory can explain certain observed behaviors and to propose an incentive system.

3.2.4.2 Case 1: Model with neither bill-back nor reward

The model used is based on the following assumptions:

- The perceived value of the tool depends on the level of involvement of the releasing and receiving site as stated in Table 3-1. The fair market value, \$500k, is achieved only when the quality of the demolition and installation is good but without any cooperation of the receiving site at the early stage of the process. However, if the receiving site decides to cooperate while the same quality of work is kept during the demolition and installation, the perceived value increases substantially to \$700k. This increase emphasizes the competitive advantage of transferring tools between sites. On the other hand, if the quality of the installation is poor, the value of the tool decreases by \$50k in both cases previously described. Finally, whatever the implication of the receiving site prior the demolition, if the releasing site decides to cannibalize the tool, the outcome is the same: if the quality of the installation is good, the value of the tool is $350k, if not the value is $320k.

	Cooperation of the receiving site prior the demolition		No cooperation of the receiving site prior the demolition	
	Good quality of installation (receiving site)	Poor quality of installation (receiving site)	Good quality of installation (receiving site)	Poor quality of installation (receiving site)
Good quality of demolition (releasing site)	$700k	$650k	Fair Market Value: $500k	$450k
Poor quality of the demolition / Cannibalization (releasing site)	$350k	$320k	$350k	$320k

Table 3-1: Perceived value of the tool

- Demolishing the tool has an intrinsic cost of $60k for the releasing site. However, if the site decides to cannibalize the tool, it can expect $120k from the parts cannibalized ($100k in parts and $20k in gain of production).

- The intrinsic cost to install the tool is $200k (333% of the demolition cost). Moreover, if the receiving site decides to bring on site the suppliers and spends the necessary time to follow the 6D procedures, the site will incur an additional cost of $15k.

- If the receiving site is involved during the first phase, it increases its cost by $10k. Indeed, it may have to spend time in visiting the tool before demolition, analyzing performance data, and so on.

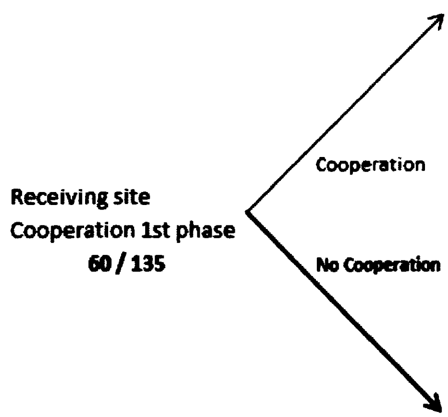
- If the tool was cannibalized, the parts taken have to be replaced so that the value of the tool match either the fair market value ($500k in the case of a good installation) or $450k in the case of a poor installation (see Table 3-1).

As mentioned previously, the final outcome is determined by two games. First, before the beginning of the demolition, the receiving site has to decide between "cooperation" and "no cooperation." Then, the releasing and receiving sites take independently their own decision in terms of quality of demolition and installation.

Before June 2006, the bill-back process did not exist. Therefore, if the tool was cannibalized by the releasing site, the additional cost of repair to bring the tool back to a functional state had to be paid by the receiving site.

Figure 3-6 summarizes the different outcomes of the game (for details of the calculations, see Appendix E). By reasoning backward, we see that the releasing site always has a dominant strategy in cannibalizing the tool. Indeed, whatever the receiving site's decision, the best interest for the releasing site is to always offset its demolition cost by a gain in cannibalization. Also, for the receiving site, the dominant strategy is to always perform a good installation of the tool. Consequently, for this part of the game, the Nash equilibrium[1] is defined by "cannibalization" and "good quality of installation." Given this result, the best strategy for the receiving site first move is "no cooperation." Indeed, by not cooperating, the receiving site increases its outcome by $10k from $125k to $135k.

		Receiving site Quality of installation: Good	Receiving site Quality of installation: Poor
Releasing site Quality of demolition 60 / 125	Good	-60 / 475	-60 / 440
	Cannibalization	60 / 125	60 / 110



		Receiving site Quality of installation: Good	Receiving site Quality of installation: Poor
Releasing site Quality of demolition 60 / 135	Good	-60 / 285	-60 / 250
	Cannibalization	60 / 135	60 / 120

Figure 3-6: Game theory analysis with neither bill-back nor reward

[1] A Nash equilibrium (named after John Forbes Nash, who proposed it) is a list of strategies, one for each player, such that no player can get a better payoff by switching to some other strategy that is available to her while all the other players adhere to the strategies for them in the list. (Dixit and Skeath 2004, p. 87)

This result is clearly suboptimal for Intel®. Indeed, if we define the outcome for Intel® by the sum of the outcomes of the releasing and the receiving sites, we obtain $195k. This result is 53% inferior to the best possible outcome, $415k, achieved with "cooperation," "good quality of demolition" and "good quality of installation."

Finally, we note that for the receiving site, the marginal gains[1] of non-cooperating and of performing a good quality installation are low (respectively $10k and $15k). Consequently, the decision may easily switch to the other alternative if other pressures than financial are exerted.

3.2.4.3 Case 2: Model with only bill-back

Recognizing that the releasing site had an incentive to cannibalize the tool and after receiving many complains from the receiving sites, the 6D Working Group, in cooperation with the Finance Department, created in June 2006, the bill-back policy (Intel 2006). The scope of this policy is to avoid the receiving site taking the financial hit for replacing any missing spare parts because of cannibalization.

In practice, the receiving site can bill-back the parts required to make the tool complete and functional according to its original intended use. This policy can be applied only to material costs. Therefore, all the additional costs (labor, production lost, etc.) are not taken into account. Consequently, based on the previous example, if the perceived value after demolition is $350k (i.e. "no cooperation," "cannibalization" and "good quality of installation"), the receiving site will spend $150k to fix the equipment: $100k in missing parts plus $50k in labor, production lost, etc. With the new policy, the receiving site will bill back $100k, leaving $50k of its own costs.

Following the same methodology as the one used in the previous case, we can construct the new decision tree (Figure 3-7).

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[1] We define marginal gain by the difference in payoffs between the best and next available strategies. For instance, the marginal gain for the receiving site for its first decision is: $135k - $125k = $10k.

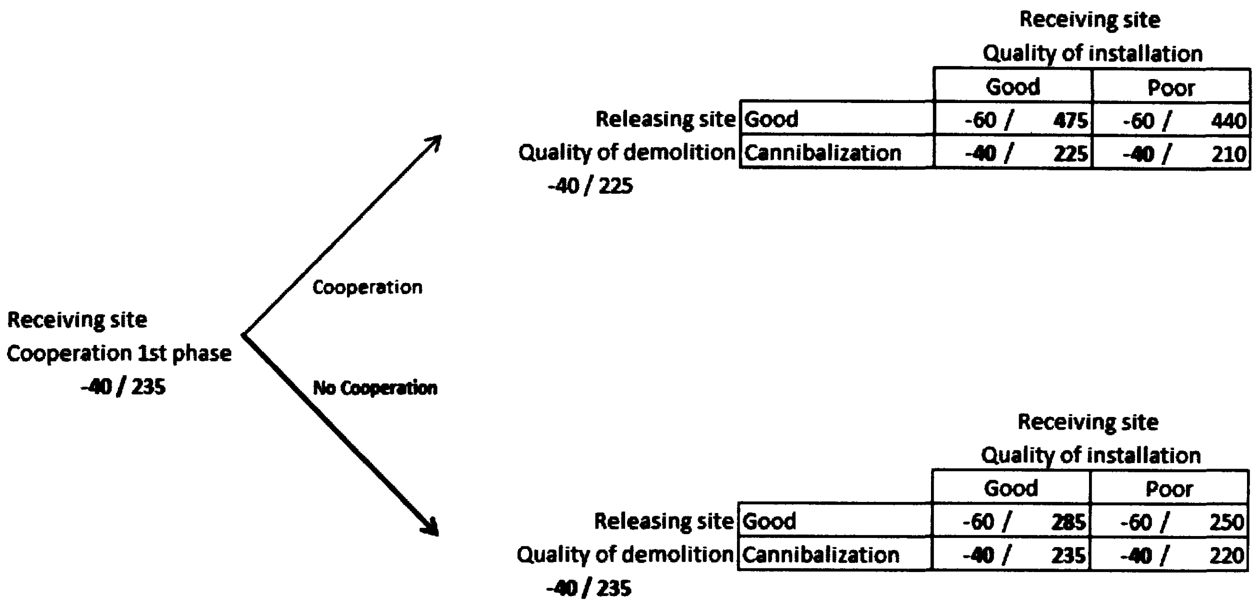

Figure 3-7: Game theory analysis with bill-back but no reward

We note that the end result does not differ from the previous case: the Nash equilibrium of the game is "no cooperation," "cannibalization" and "good quality of installation." Even if the main objective of the bill-back process is achieved (the receiving site does not pay anymore for the missing pieces and therefore increases its payoff by $100k), the outcome for the whole corporation remains the same: the aggregate value of the tool is $195k.

Three observations can be drawn from this model. First whatever its decision, the releasing site always obtains a negative payoff. This specific point is problematic. Indeed, when IRC sells a tool to a third party at the fair market value, it will share the gain with the releasing site. Therefore, in order to maximize its payoff, the releasing site has an incentive to execute a good demolition. Since human resource is a constraint, it may happen that priority is given to demolish a tool with positive payoff. Second, Table 3-2 summarizes the evolution of the marginal gains. As expected the marginal gain of cannibalizing the tool decreases by $100k from $120k to $20k. The other marginal gains for the receiving site remain the same at $10k and $15k. The fact that all these gains are small implies that the decisions may easily switch if pressures other than financial are considered. Finally, the bill-back policy penalizes cannibalization without offsetting its gain. Therefore the incentive to cannibalize the tool, even if small, remains. One possible solution may be to increase the penalty. However, this may not be feasible and politically accepted because it would be seen more as a punishment than a tool to foster constructive behaviors.

	Marginal gain without bill-back	Marginal gain with bill-back
Receiving site: Cooperation <=> No cooperation	\$10k	\$10k
Releasing site: demolition Good <=> Cannibalization	\$120k	\$20k
Receiving site: installation Good <=> Poor	\$15k	\$15k

Table 3-2: Comparison of the marginal gain with and without bill-back

3.2.4.4 Case 3: Model with both bill-back and reward

Instead of raising the penalty, we can create a reward system that will ultimately drive the releasing and the receiving sites toward better results. The attributes of this system must be:

- Highest possible payoff for Intel (i.e. "cooperation," "good demolition" and "good installation").
- Positive payoff for every player,
- High marginal gain to make the best decision obvious for all, and

The proposed solution is the transfer of capital from the receiving to the releasing site:

The receiving site pays half of the fair market value (given by Intel Resale Corporation) to the releasing site.

However, if the tool was cannibalized, the receiving site can bill-back the parts required to make the tool complete and functional according to its original intended use. Moreover, if the receiving site follows the appropriate installation procedures, it can refuse to pay half of the fair market value.

Given this new policy, the receiving site will not pay in only two configurations: "cooperation", "cannibalization" and "good installation", and "no cooperation", "cannibalization" and "good installation."

Figure 3-8 shows the consequences of this new policy.

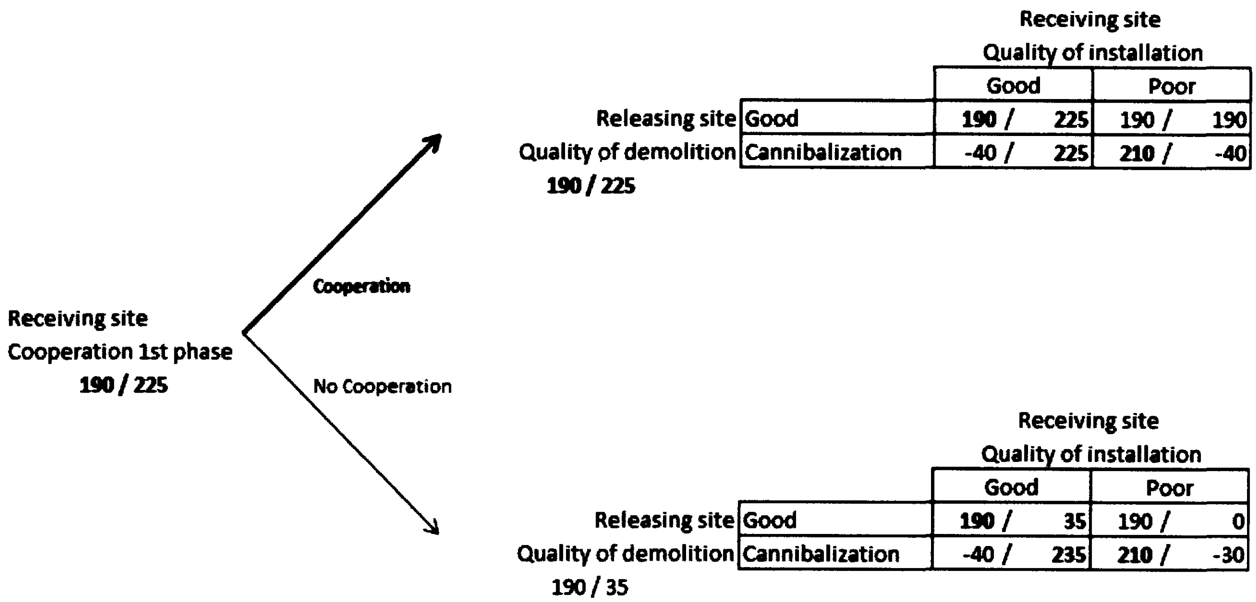

Figure 3-8: Game theory analysis with bill-back and reward

This solution meets the three criteria previously stated: the expected solution is "cooperation", "good demolition" and "good installation," and every player has a positive payoff. Finally, the marginal gain for each decision is significant as seen in Table 3-3.

	Marginal gain without bill-back	Marginal gain with bill-back	Marginal gain with bill-back and reward
Receiving site: Cooperation <=> No cooperation	\$10k	\$10k	\$190k
Releasing site: demolition Good <=> Cannibalization	\$120k	\$20k	\$230k
Receiving site: installation Good <=> Poor	\$15k	\$15k	\$35k

Table 3-3: Comparison of the marginal gain with and without reward

3.3 Conclusion

In this chapter, we started with an analysis of the organization through three lenses: strategic design, political and cultural. Even if, by design, the three classic levels of process management (strategic, tactical and operational) exist, we saw that global changes in the tool reuse program cannot be executed without political power and a cultural shift. Indeed, the "not invented here" syndrome driven by an engineering culture and incentives rewarding innovation over sustaining activities may explain differences between sites in organizational structures and willingness to follow a global initiative. The difficulties in driving global initiative changes were especially emphasized with the description of how Copy EXACTLY! was implemented.

The objective of the 6D Working Group is to design processes that ultimately help releasing and receiving sites to deliver consistent quality. However design is not execution. Moreover, compliance to processes does not guarantee quality of the final result: first, because culturally, sites want to be accountable for results, and second, because the structure may lack leadership figures focused only on the execution part from end-to-end.

Finally, these activities must be linked together by a common goal. Presently, local sites have their own incentives that may not align with close cooperation between sites and quality of work. The proposed solution, which consists in an exchange of money between the receiving and releasing sites, should help improve this situation.

4 Process improvement framework

In the previous two chapters, we described the 6D processes and the leadership challenges in their implementation. In this chapter, we analyze tools to improve these processes. First our focus will be on a Lean and System Dynamics Thinking. Second, we will review the set of metrics in place to see whether they measure the activities that should be improved. Finally, we will conclude our discussion about standardization.

4.1 Literature Review

This section presents an overview of Lean and System Dynamics Thinking and how these tools can be applied to improve the 6D Program and create a Learning Organization.

4.1.1 Lean thinking

Over the last twenty years, the literature describing Lean and its application in a manufacturing setting has been abundant. While Lean techniques have been around longer (Ohno 1978), the term "Lean" was first introduced in 1988 by a graduate student, John Krafcik, while he was working in the International Motor Vehicle Program at MIT. Three years later, James P. Womack immortalized the term in the book *The Machine that Changed the World* (Womack, Jones and Roos 1991) describing the Toyota Production System. The idea of Lean is to do more with less, or in other words, eliminate waste. From an enterprise point of view, Lean can be defined as: "Correctly specify value for the customer, avoiding the normal tendency for each firm along the value stream to define differently to favor its own role in providing it. Then identify all the actions required to bring the product from concept to launch, from order to delivery, and from raw material into the hands of the customer. […] Next, remove any actions which do not create value and make those actions which do create value proceed in continuous flow as pulled by the customer. Finally, analyze the results and start the evaluation process over again."(Womack and Jones 2003, p. 276) As pointed out by this quote, the objective of waste removal is achieved through five steps: value identification, value stream identification, flow time reduction, pull from the customer, and continuous improvement by workers.

A Lean thinking framework is not the sole improvement program. For instance, Six Sigma focuses on reduction of variations. Through extensive and structured statistical analysis, fluctuations can be minimized and output becomes more predictable. The main assumption is that data analysis can provide a different perspective on the process. Another common improvement program is Theory of Constraints (Goldratt 1994). Contrary to Lean and Six Sigma which respectively focus on flow and variations, the Theory of Constraints focuses on system improvement. By subdividing the system in a series (a chain) of independent processes, it becomes easier to first identify the constraint, second exploit the constraint (i.e. improve and run the targeted process at maximum capacity), third subordinate everything else to the constraint, and fourth elevate the system's constraint (i.e. major improvement to eliminate the constraints, such as capital investment) (Goldratt 1990, p. 58-63). Therefore the main assumption of the Theory of Constraints is that processes are independent and can be improved independently. Moreover, since the focus is on a single process, it does not leave much room for worker input and incremental improvements by workers on their own (Nave 2002).

Deciding which improvement program to put in place depends on the type of process, the nature of the issues, the objective, and the corporate culture. For instance, Theory of Constraints may not be suitable for the 6D Program. Indeed, the definition of a constraint in tool demolition activities may not be as straightforward as in manufacturing processes; the constraint may vary from one tool to another. Moreover, the main objective of Theory of Constraints is to increase throughput. Even if it may be a legitimate objective for the 6D Program, safety, quality of the demolition, and on-time delivery may be more suitable (see Question 3 of the survey Appendix C). Finally, following the previous Chapter about process management, the corporate culture may not fit with the management style required in a Theory of Constraints program. Similarly, for Six Sigma, the main objective of uniform process output may not bring value to the 6D program. Moreover, the infrequent and highly customized nature of tool demolitions may not allow the extensive use of statistical analysis.

In contrast, focusing on process flow with reduction of waste (*muda*) and small improvement (*kaizen*), which characterize Lean, may bring something to the 6D Program.

However the definition of waste may differ from the original seven categories[1] as stated by the creator of the Toyota Production System, Taiichi Ohno, in *Toyota Production System: Beyond Large-Scale Production* (Ohno 1978). Indeed, the 6D Process covers not only the execution of the demolition but also the planning of the activities, and the transmission of information between sites. In his book *Office Kaizen* (Lareau 2002), William Lareau defines twenty-one types of waste that can occur in an office environment. Some of these such as goal alignment waste (energy expected by people working at cross-purposes and the effort required to correct the problem and produce a satisfactory outcome), scheduling waste, waiting (for information, signature, etc…), or translation wastes (change data, formats, and reports between process steps and owners) must be considered too.

Generally people associate Lean with its tools: for instance, value stream mapping, visual control, and five-why's, etc. However, the highest benefit comes from the understanding of Lean rules and principles. Indeed, applying tools without knowledge may lead to frustration and common-sense conclusions as pointed out by Roy C. Wildeman (Wildeman 2005). Moreover most of these rules can easily be applied to improve repetitive operations (manufacturing or services), but may be cumbersome and inadequate for complex and infrequent activities such as the demolition of tools.

In 1999, Steven Spears and H. Kent Bowen published an article, *Decoding the DNA of the Toyota Production System* (Spear and Bowen 1999), describing the Toyota Production System. The conclusion of their four-year study of more than forty plants is a set of four rules that ultimately helps to unravel the paradox that "activities, connections, and production flows in a Toyota factory are rigidly scripted, yet at the same time Toyota's operations are enormously flexible and adaptable." These four rules have been adopted by Intel® and constitute the

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[1] 1) Overproduction and early production producing over customer orders, producing unordered materials / goods. 2) Waiting hanging around, idle time (time when no value is added to the product). 3) Transportation handling more than once, delays in moving materials, unnecessary moving or handling. 4) Inventory: unnecessary raw materials in stores, work in process (WIP), and finished stocks. 5) Motion: movement of equipment or people that add no value to the product. 6) Over-processing: unnecessary processing or procedures (work carried out on the product which adds no value). 7) Defective units producing or reworking scrap.

foundation of the Lean House (Figure 4-1) used by Intel®'s mX (manufacturing excellence) group to teach and propagate Lean.

Figure 4-1: The "House" of Manufacturing Excellence principles

Rule 1: All work shall be highly specified as to content, sequence, timing, and outcome. The underlying reason of this rule is to make problem detection simpler. Indeed, a variation may have two origins: the design or its execution. Therefore, without structured and standardized work specifications, learning and improvement opportunities are hidden. That is the reason why the 6D Working Group focuses most of its effort on pushing the creation and the use of the 2D Checklists. The second justification of this rule is that "rigid specification is the very thing that makes the flexibility and creativity possible" (Spear and Bowen 1999). Indeed, the Toyota Producing System emphasizes continuous improvements made through scientific experimentations (hypothesis, plan, expected results, test). Should the work not highly specified, this method would not work. However, in Section 4.3, we will see that because of the nature of the work (complex and infrequent) and the objectives of the different organizations, the attempt at standardizing processes may have unexpected consequences. Therefore, it may be necessary to clearly define the adequate level of standardization allowing at the same time efficiencies for the Fabs and continuous improvement for the organization.

Rule 2: Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses. While the first rule describes how individual work is performed, the second rule illustrates the relation between activities. By following this rule, groups avoid confusion and loss of information. An attempt has been made to map the interactions occurring during the transfer of a tool between two sites (see appendix F). The number of connections shows the complexity of the organization in place and clearly highlights opportunities for improvement.

Rule 3: The pathway for every product and service must be simple and direct. This rule explains how the system is constructed and which step is essential or not. The objective is to eliminate all non-value added steps by simplifying and specifying every step. It also means that a task has to be done not by the next available person but rather by a specific designated person. For the 6D Program it means that not only the processes have to be specified but also the people who do the work clearly identified in advance. By doing so, the non-value added time between activities can be minimized. In some plants, prior major demolition activities, a "map day" is led by the SPoC. By drawing all the activities performed and their interrelation, the participants can optimize the pathway and ensure that each task is assigned to a specific person.

Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization. The objective of this rule is to provide a framework of how to improve. Following the story of Bob Dallis depicted in *Learning to Lead at Toyota* by Spear (S. J. Spear 2004), we can identify four components of this process improvement method. First, the proposition of change should result of direct observation, not reports, interviews, aggregate data or statistics. Second, the "proposed change should always be structured as experiments." In other words, "if we make this change, then we expect this result." Third, "workers and managers should experiment as frequently as possible." This lesson is linked to small incremental changes. Finally, "managers should coach not fix." Indeed, the most appropriate person to detect and perform a change is the worker, not the manager. Therefore, the manager must be seen more as a teacher or a coach than a technological specialist.

Linked to these four rules, Intel® also uses a set of five principles described in *The Hitchhiker's Guide to Lean* by Flinchbaugh, Calino and Pawley (Flinchbaugh, Carlino and Pawley 2006). The principles described below constitute the pillars and the roof of the Lean House (Figure 4-1).

Principle 1: Directly observe work as activities, connections and flows. This principle emphasizes the need to focus on processes as they are done instead of just apparent results. Indeed, people can improve only if they deeply understand current reality.

Principle 2: Systematic waste elimination. As stated previously, the systematic waste elimination has to be handled at the lowest possible level. For the 6D Program, it means that the Tool Owner and the operators working on the demolition of a tool must take an active part in improving the processes.

Principle 3: Establish high agreement of what and how. This principle is linked to the concept of standardization. However, contrary to the common meaning of "standardization" which implies only the "how," high agreement implies that "the people closest to an activity or process should be in agreement about what and how an activity or process should be accomplished" (Flinchbaugh, Carlino and Pawley 2006, p. 16). This high agreement is especially important because "if people are not engaged to believe in this principle, it is likely they will undervalue the tools and ultimately undermine them" (Flinchbaugh, Carlino and Pawley 2006, p. 18).

Principle 4: Systematic problem solving.

Principle 5: Create a Learning Organization. This last principle is central in a Lean implementation because "it holds the other four principles together" (Flinchbaugh, Carlino and Pawley 2006, p. 23). Based on Senge's work (Senge 1990), the five characteristics of a learning organization are: 1. Personal Mastery (ability to see the reality as it is and measure the gap between this reality and a goal), 2. Mental Models (ability to compare reality or personal vision with perceptions), 3. Shared vision (ability of a group to share a vision), 4. Team Learning (ability of a group to engage in "dialogue" rather than "discussion"), and 5. System Thinking (see Section 4.1.2). Especially for the 6D Program, process sharing is one of the main objectives of the program. However, the decentralized nature of the organizations in place, the low frequency and the complexity of the activities make learning even more difficult.

Often people describe Lean implementation as a journey. Indeed, Lean is more a cultural change than a set of tools and techniques than can be applied to punctually optimize a system. "Veterans of successfully leading lean manufacturing efforts always emphasize that this is a cultural change, not just a technical change." (Senge 1990, p. 101). Based on a clear set of rules and principles, the goal is incremental improvement of activities, connections and flows at the lowest level possible. However, it is important to mention that the focus is on employee participation as opposed to low level decision making or autonomy. "Despite its democratic appearance, the *ringi* system[1] actually has little in common with a participative method of management." (Odaka 1975). Every work, experiment and communication is codified and standardized. Only through these highly specified activities, can improvement and even flexibility be made possible.

To conclude, for a successful Lean implementation, the 6D Working Group may have to clearly define the level of responsibility of each of the tasks to be performed and improved. Based on the principle that improvement has to be made at the lowest level possible, it may have to leave some flexibility to individual sites and only focus on the optimizing high level flow between sites. This point will be covered in details in Section 4.3.2.

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[1] The Japanese decision making system

4.1.2 System dynamics thinking

By its own nature, Lean is essentially an operational tool. It provides a framework for focused improvement activities with very tangible performance measures (for instance cycle time, level of stock, or quality). But on a more strategic level, a systems dynamics thinking approach may be a good complement. For instance, the lean concept of just-in-time to reduce inventory level is often offset by increases in inventory held by the suppliers to meet more frequent and reliable delivery requirements (Sterman 2000, p. 787). A systems dynamics approach can help in determining the adequate level of inventory each player must hold in order to minimize the aggregate inventory coverage and still cover market fluctuations.

System dynamics was first introduced by Jay Wright Forester in an article, *Industrial Dynamics - A Major Breakthrough for Decision Makers*, in the 1958 Harvard Business Review (Forester 1958). Further developments have been produced by researchers to apply system thinking techniques in economy, social behavior, climate change, and other areas. In 1990, Peter Senge published *The Fifth Discipline* (Senge 1990), followed by *The Fifth Discipline Fieldbook* (Senge, Ross, et al. 1994) and *the Dance of Change* (Senge, Ross, et al. 1999), which covers the concept of learning organizations and spreads system thinking as a management tool.

System dynamics was created to solve dynamic complexity, per opposition to detail complexity. "Most people think of complexity in terms of the number of components in a system or the number of combinations one must consider in making a decision. The problem of optimally schedule an airline's flight and crews is highly complex, but the complexity lies in finding the best solution out of an astronomical number of possibilities. Such needle-in-a-haystack problems have high levels of combinatorial complexity (also known as detail complexity). Dynamic complexity, in contrast, can arise even in simple systems with low combinatorial complexity. [...] Dynamic complexity arises from the interactions of the agents over time." (Sterman 2000, p. 21). Cause and effect distant in time and space, feedback, and nonlinearity (effect not proportional to the cause) are the elements of dynamics complexity that are generally misinterpreted by people. For instance, an event-oriented view of the world leads to decisions based only on the current state of our environment, while a feedback view of the world will see the interaction between the decision and the environment: today's decision will alter tomorrow's environment, leading to new decisions, and so forth.

As mentioned previously, every system is composed of feedback loops. The two basic building blocks are positive and negative feedback loops (Figure 4-2). Positive (or reinforcing) feedback loops are self-reinforcing. For instance, if I leave some money in a bank account, this amount will grow exponentially thanks to increasing interest generated. On the other hand, negative (or balancing) feedback loops tend to be self correcting: the action counters the cause. For instance, I may have a huge amount of work that pushes me to work hard. By working hard, I will reduce this amount of work that will ultimately allow me to work less. If nothing stops the decrease, the final value will be zero. However a different type of balancing loop can have a goal. In this case, the system will compare the actual value to the goal and the system will tend to reduce the gap. These two basics types of loops are the simplest examples of system dynamics models.

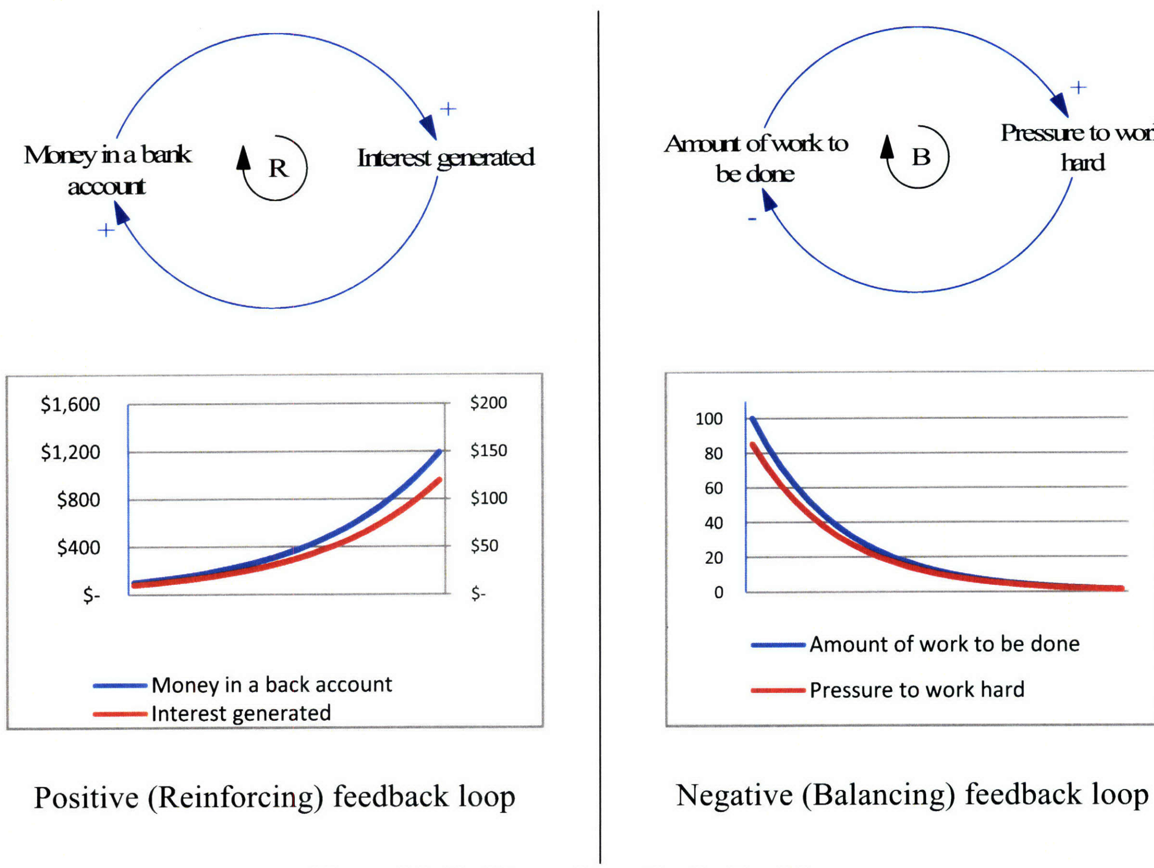

Figure 4-2: Positive and negative feedback loops

One specific thing to remember is that system dynamics is a tool designed to increase our understanding of the true causes of behaviors. Through models, it can enhance our learning of dynamic complex systems. Figure 4-3 illustrates current ideas for successful learning and emphasizes the relation between the real world and virtual worlds (formal model, simulations). Virtual worlds have the advantages of providing low-cost and low-risk laboratories for learning. However, they have their pitfalls too. Indeed, systems thinking is derived from the process control engineering discipline, therefore it requires one to apply the principles of the scientific method (hypothesis, test, analyze, then conclusion). Consequently, systems thinking tools have to be used with a specific question in mind. For instance, in Section 4.3.1, we will study why people in Fabs have difficulties following standardized procedures (2D Checklists). Thanks to the model created, we will be able to draw more general conclusions on what should be the adequate level of standardization.

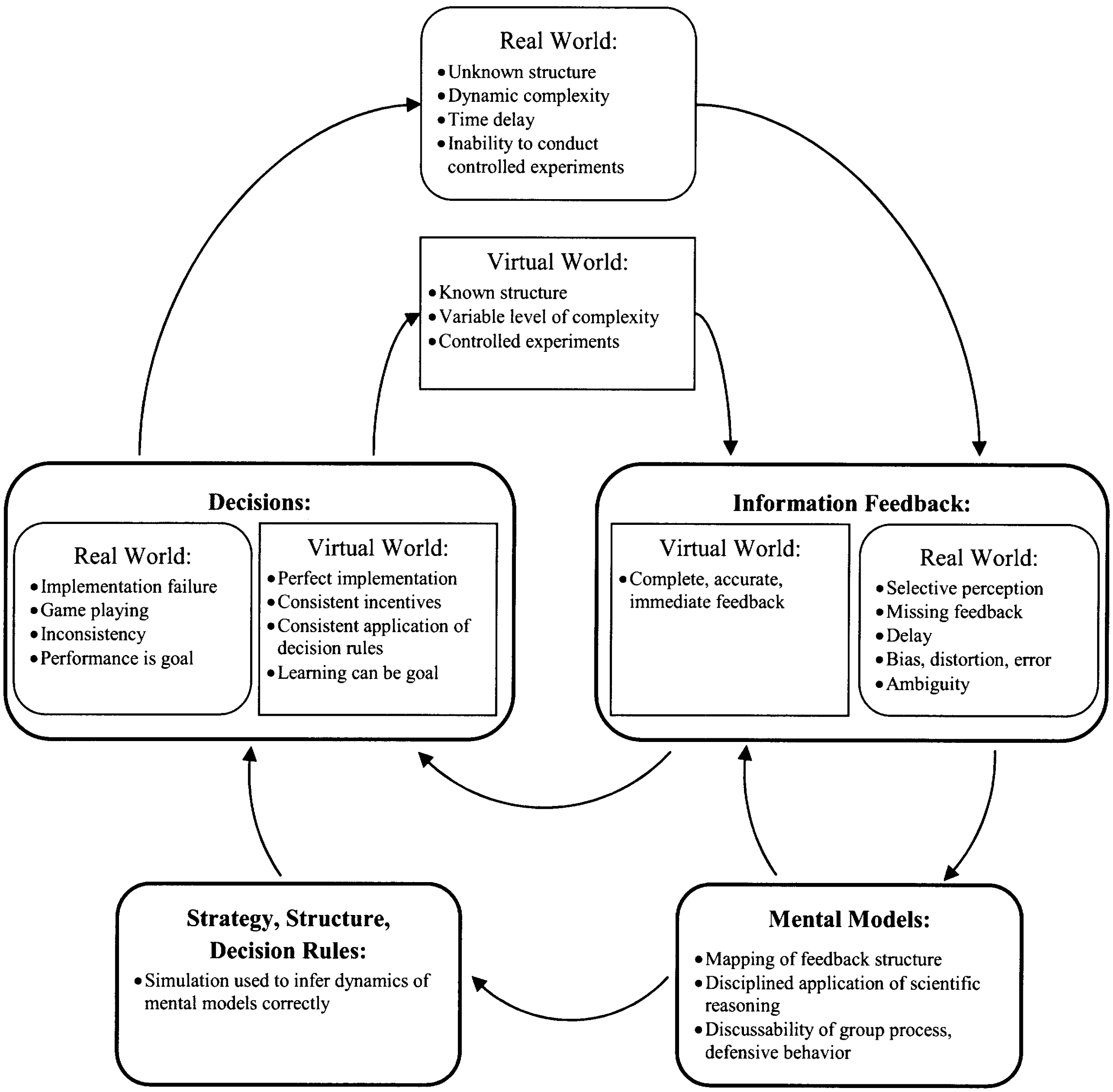

Figure 4-3: Learning Process[1]

4.2 Metric definitions

First and foremost, when we talk about process improvement, we must define the strategic objectives and associate metrics to fix goals and measure improvement opportunities. Metrics are important when designing a process because they help one to understand and manage the

[1] Source: (Sterman 2000, p. 34)

activities. Moreover, they offer incentives and guidance for the executants. As stated by Kaplan and Norton, "What you measure is what you get" (Kaplan and Norton 1992). Therefore, first, we will analyze the actual metrics with respect with the strategic objectives and the key processes. Second, we will review the characteristics of a good set of metrics. Finally, we will propose a new set of metrics that should pull people toward the overall mission of the 6D Program.

One of the main problems in the conception of metrics is the availability and reliability of the data. For instance, most of the assessments of the releasing site performance rely on the receiving site feedback (called Receiving Site Certifications). In 2007, less than twenty percent of these feedbacks were received. On a certain measure, the proposed set of metrics will deal with this issue, but the author considers that this lack of data comes more from an execution issue than from a design issue as discussed in Section 3.2.

4.2.1 Assessment of actual metrics

The 6D program was created at the end of 2004 in a reactive mode to address major safety issues in tool demolition. Therefore the first type of metrics put in place was the number of incidents during demolition and reuse of tools. The objectives were to ensure safety of Intel®'s personnel as well as legal requirements when the tools were sold. Soon after, to tackle reliability issues, the group created a measure of incidents to narrow down the origin of the defects. Following Intel®'s guidelines, each incident was also classified by severity: 1 – High severity (Capital loss > $200k / Missed ramp-up / Accident or injury), 2 – Medium severity (Capital loss between $20k and $200k / Caused schedule compression / Unauthorized cannibalization), and 3 – Low severity (Capital loss < $20k / Procedural or price issue / No safety issue). Finally, the compliance score was put in place as discussed in Section 3.2.

However, safety, asset preservation and compliance are not the only foci of the 6D Program. Based on the survey made in October 2007 (appendix C) and interviews with several shareholders, the strategic objectives of the group include other key aspects such as on time delivery, elimination of rework, short cycle time, cost minimization, and continuous improvement.

In order to see whether the actual set of metrics (see appendix G) is aligned with theses strategic objectives, the author created an X-matrix as attached in appendix H. The X-matrix is a tool created by the MIT Lean Aerospace Initiate (LEA) to represent potential interactions between strategic objectives, metrics, key processes and stakeholder values (Nightingale and Stanke 2005).

As expected the safety and the incident parts are well covered. However other areas such as cycle time, cost control or on time delivery are weak, especially considering the inaccuracy of the compliance score. Indeed, no metric reliably measures time or commitment to a predetermined schedule. Also, we note that the indicators *Late Releasing Site Certification* and *Late Receiving Site Certification* do not really cover any strategic objectives; they only measure compliance to the process. Certainly these certifications contain information about cycle time, reliability of the tool, but these data are not formally translated into other indicators.

4.2.2 Characteristic of a good set of metrics

A good set of metrics should pull people toward the overall vision of the group. Kaplan and Norton, with their balanced scorecard framework (Kaplan and Norton 1992) argue that these indicators should answer the four following questions:

1. Customer perspective: How do customers see us? – Time, quality, performance and service, and cost are the main categories that should be assessed.

2. Internal perspective: What must we excel at? – This question links internal competencies and processes with the overall corporate objectives. Cycle time, quality, productivity and cost are directly influenced by employee's actions. Therefore each of these categories must be decomposed in specific measures at the employee level. Thus, clear targets will drive actions, decisions and improvement activities.

3. Innovation and learning perspective: Can we continue to improve and create value? – This question focuses on the internal skills of the employees. Ability to innovate, improve, and learn contribute in increasing shareholder value.

4. Financial perspective: How do we look to shareholders? – This perspective assesses whether the implementation and execution of the company's strategy is contributing to bottom-line improvement.

Also, as mentioned by Lareau in *Office Kaizen*(Lareau 2002), the set of metrics should follow the eight following characteristics:

- Actionality: This characteristic is linked to the level of control the people have on the metric they are responsible for. If their actions cannot influence the result, the metric is useless as a leading indicator. For instance, the Resale Credit to Fabs has a very low actionality for the Fabs since the resale is done through IRC.

- Proximality: Proximality means that the metric should be close to the process measured (in physical proximity and time). For the 6D Program, this can be an issue. Indeed, assessing the reliability of the tool can only be done by the receiving site while the actual work was performed in another site and the tool transfer through a warehouse. In several cases, the lead time between demolition and reinstallation may last more than six months.

- Immediacy: Immediacy means that a change in the input has a fast impact on the metric.

- Causality: A metric should assess a cause rather than an effect.

- Proportionality: Since performance may be composed of many measurable components, it is important to choose those that have the most direct statistical relationship.

- Atechnology: The method used to calculate the metric should be easy enough to be understood by the people responsible for improving the process.

- Teamness: It may be better to create a metric engaging intact work groups in meaningful, focused improvement efforts more than individuals.

- Customer Focus: Customer focus reflects performance relative to internal and/or external customer requirements rather than "business" concerns or bureaucratic reporting concern.

4.2.3 Proposed new metrics

Based on the previous discussion and in particular the Kaplan-Norton approach, the following tables provide suggestions for new metrics.

4.2.3.1 Internal focus metrics

This set of metrics focus on key internal outcomes of the 6D processes: safety, reliability of the tool, duration of the demolition, and documentations.

		Strategic Objectives									Characteristics							
Name	Definition	Minimize cost	Eliminate rework (Releasing site)	Short cycle time	Deliver on time	Reliability of the tool (receiving)	Continuous Improvement	Preserve Intel's asset	Eliminate Safety Incident	Responsibility / Accountable	Actionality	Proximality	Immediacy	Causality	Proportionality	Atechnology	Teamness	Customer Focus
Safety incident rate	Number of safety incidents (1 year rolling)									Plant Manager								
%TTFS Missing	= 1 - Number of TTFS answered / Number of tools installed. 1 year rolling									TO								
%neg TTFS by releasing site	= Negative TTFS / TTFS answered. 1 year rolling									TO								
Missing 2D checklists	= 1 - Number of 2D checklists created / Number of tools demolished. 1 year rolling									SPoC								
Missing TRANS Template	= 1 - Number of TRANS Template created / Number of tools demolished. 1 year rolling									SPoC								
Duration of 2D	Absolute value of the difference between what was agreed and was was done									SPoC								
Duration of 3D	Absolute value of the difference between what was agreed and was was done									SPoC								
Duration of transportation of the tool	Absolute value of the difference between what was agreed and was was done									TTC								
Total duration	Absolute value of the difference between what was agreed and was was done									TO								
% of reworked after DSL1	= Number of DSL1 reworked / Number DSL1 at the end of 2D. 1 year rolling									TO								
% of reworked after DSL2	= Number of DSL2 reworked / Number DSL2 in the middle of 3D. 1 year rolling									TO								

Code
1 Slightly meet the characteristic
2 Meet the characteristic very well

Table 4-1: Internal focus metrics

4.2.3.2 Customer focus metrics

This set of metrics focus on customers. In this case, customer is defined either by the receiving site or by Intel® Corporation.

		Strategic Objectives									Characteristics							
Name	Definition	Minimize cost	Eliminate rework (Releasing site)	Short cycle time	Deliver on time	Reliability of the tool (receiving)	Continuous Improvement	Preserve Intel's asset	Eliminate Safety Incident	Responsibility / Accountable	Actionality	Proximality	Immediacy	Causality	Proportionality	Atechnology	Teamness	Customer Focus
Issue per Fabs	# of issues. Pareto									SPoC								
Number of undocumented cannibalizations										TO								
TTI / M: Time to installation / market										SPoC								
Number of people involved per demo										SPoC								
% On time delivery										SPoC								

Code

1 Slightly meet the characteristic
2 Meet the characteristic very well

Table 4-2: Customer focus metrics

4.2.3.3 Innovation and learning metrics

This set of metrics focus on the ability of the sites to learn, innovate and improve existing processes. Especially, many indicators measure the number of action plans implemented after defects are found. Finally, to foster process sharing and innovation, each TO will have to propose two best practices after each demolition.

		Strategic Objectives									Characteristics							
Name	Definition	Minimize cost	Eliminate rework (Releasing site)	Short cycle time	Deliver on time	Reliability of the tool (receiving)	Continuous Improvement	Preserve Intel's asset	No Safety incident	Responsibility / Accountable	Actionality	Proximality	Immediacy	Causality	Proportionality	Atechnology	Teamness	Customer Focus
% people having received 6D training										SPoC								
Action plan implemented	Number of action plans closed / Number negative TTFS opened. 1 year rolling									SPoC								
% Safety action plans implemented	Number of action plans closed / Number safety incidents. 1 year rolling									6D Program Manager								
Number of Safety Action Plans open after X months										6D Program Manager								
% TO providing 2 best practices at the end of demolition	A the end of each demolition, the TO should fill 2 learning / best practices.									TO								

Code

1 Slightly meet the characteristic
2 Meet the characteristic very well

Table 4-3: Innovation and learning metrics

4.2.3.4 Financial metrics

Finally the forth set of metrics is related to financial aspect of the demolition. Especially, deviations from agreed budget are measured per site. However, this set of metrics cannot be put in place without a standardized and accurate way of measuring these costs. (Bodmer 2007) proposes a cost analysis model that can be used by every Intel® site.

		Strategic Objectives									Characteristics							
Name	Definition	Minimize cost	Eliminate rework (Releasing site)	Short cycle time	Deliver on time	Reliability of the tool (receiving)	Continuous Improvement	Preserve Intel's asset	Eliminate Safety Incident	Responsibility / Accountable	Actionality	Proximality	Immediacy	Causality	Proportionality	Atechnology	Teamness	Customer Focus
2D within budget	= Amount spent - agreed plan	orange								TO	orange	orange	orange	orange	green	green	green	orange
3D within budget	= Amount spent - agreed plan	orange								TO	orange	orange	orange	orange	green	green	green	orange
Demolition within budget	= Amount spent - agreed plan	green								TO	orange	orange	orange	orange	green	green	green	orange
Installation within budget	= Amount spent - agreed plan	orange								TO	orange	orange	orange	orange	green	green	green	orange
Total abnormal costs	cost of cannibalization	orange				orange				6D Program Manager					green	green	green	orange
Total cost per tool	include convertion kits	green								6D Program Manager					green	green	green	green

Code
1 Slightly meet the characteristic
2 Meet the characteristic very well

Table 4-4: Financial metrics

4.3 Standardization of processes

In Section 3.2, the question of standardization was raised with the discussion about compliance and accountability. Especially, given the result of our survey, it seems that mature sites see the 6D Working Group more as consultants providing suggestions than as architects providing standardize procedures and checklists to manage a demolition. However, when these same sites are asked to prioritize the actions of the 6D Working Group, a huge majority rank first "standardization of processes" (Appendix C – Question 8).

Therefore, finding the appropriate level of standardization seems to be a subtle exercise. On one hand standardization offers clear benefits. As highlighted in the Section about Lean, it allows process designers and leaders to find gaps and improvement opportunities to clearly target actions. Moreover, high level of standardization across the Fabs simplifies process sharing and facilitates learning. However, because of changes over time, tool configurations may differ from site to site. Not only are configurations different but also organization, way of thinking and culture do not follow Copy EXACTLY!.

This question about standardization and autonomy is not specific to Intel®. In 1991, Jan Klein in *A Reexamination of Autonomy in Light of New Manufacturing Practices* analyzed three plants[1] which tried to copy Japanese production methods in introducing Just-in-time and standardization. She summarizes the tension between standardization and autonomy as follow: "A cornerstone of continuous improvement is the initial standardization of tasks. Once tasks have been standardized, they can be improved. [...] Such standardization allows problems to be more easily investigated and solved; since there is less noise in the system, root causes of difficulties can be better isolated. But such standardization implies eliminating variation, e.g., different ways of thinking or approaching specific tasks, between people to the greatest extent possible. Hence, the clash with autonomy: providing autonomy means that individuals differences are allowed to arise, standardization aims to minimize those differences."(Klein 1991, p. 28)

In order to answer this question of standardization, we first study a specific example, the 2D Checklist, using a system dynamics model, then draw more general conclusions to provide guidelines about what should be standardized and how.

4.3.1 System dynamics model of the 2D Checklist

As seen in Section 2.3.2.1, the 2D Checklist is a document describing the sequence of tasks to be performed to safely and efficiently decontaminate and decommission a tool. For the 6D Working Group, this is an important piece that the tool owner must prepare before every 6D event. To help him in his task, the 6D Working Group shares a proven 2D Checklist. However, it seems that few use this tool and often 2D Checklists are signed without being followed.

To understand the underlying reasons of this behavior, a system dynamics model (Figure 4-4) based on the "accidental adversaries" archetype was created. "This archetype explains

[1] Tektronix, a manufacturer of oscilloscopes, New United Motors Manufacturing (NUMMI), and a diesel engine manufacturing plant.

how groups of people who ought to be in partnership with each other, and who want to be in partnership with each other, end up bitterly opposed" (Senge, Ross, et al. 1994, p.145).

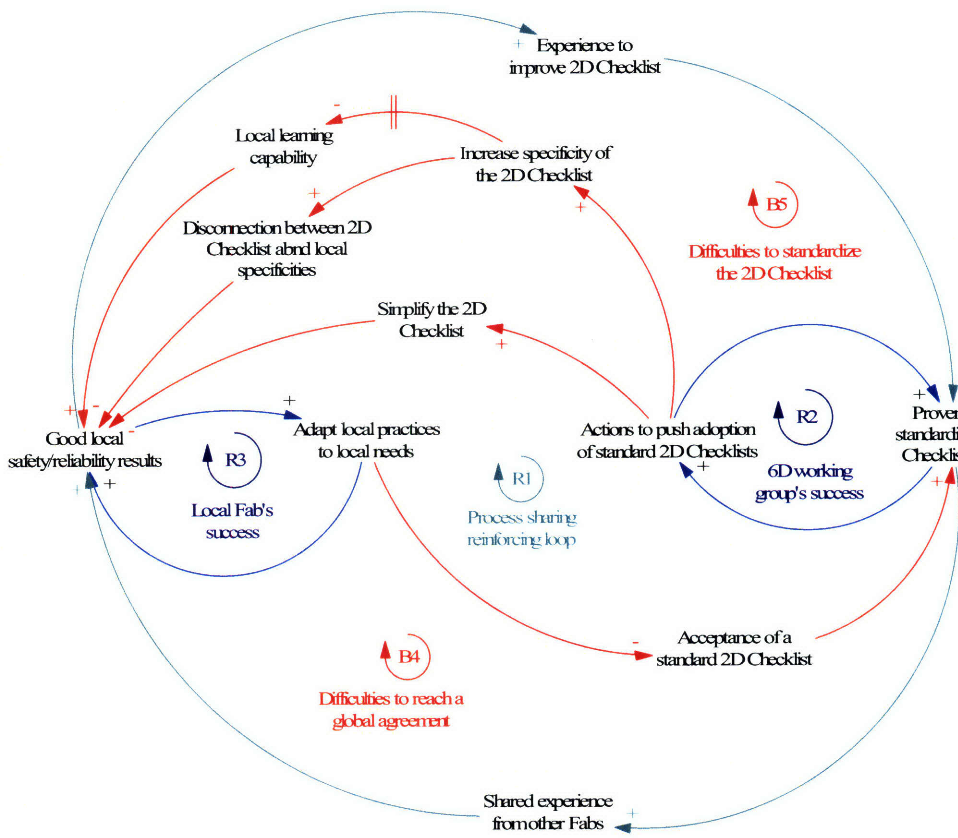

Figure 4-4: System dynamics model of the 2D Checklist standardization effort

On the left side of the model, "Good local safety/reliability results" is the goal of local Fabs. On the right side, "Proven and standardized 2D Checklists used" is the goal of the 6D Working Group. Both parties recognize that by sharing experience, they can mutually support each other success (as represented by the reinforcing loop R1).

However, an easier and faster way exists to improve success. For the 6D Working Group, its success can be achieved by blindly pushing the adoption of standard 2D Checklists (reinforcing loop R2). This is done through training, the constitution of a user-friendly database, and compliance indicators. On the Fab side, the easiest way to obtain good results is to base its 2D Checklist on existing procedures and local competencies (reinforcing loop R3).

These local self-enhancement activities would be fine except that they have unintended consequences. Both are responding more attentively to their needs than to the ones of their partner. As represented by the balancing loop B4, "adapting local practices to local needs" has a negative influence on "acceptance of a standard 2D Checklist." Indeed, even the TOs who participated to the creation of the process are now reluctant to propose any modifications: "Everybody is doing differently so it is impossible to agree on a single procedure."[1] From the 6D Working Group point of view, whatever actions they may take will have a negative effect on local results (balancing loop B5). Indeed, simplifying the standard 2D Checklists while enforcing their use will end up in a decline of local results since a novice TO will not be able to demolish a tool safely, on schedule and effectively. On the contrary, making them even more specific and complex may, in the short term, causes unneeded work by pushing the one-size-fits-all solution while each tool has its own specificities. Also, in the long term, it has a pernicious effect; the TOs will never learn how to deal with local specificities by themselves (for more details, see "Special case: Shifting the burden to the intervenor" in (Senge 1990, p. 393)).

This analysis points out how local activities, with the best intentions, can lead to an overall limiting development of the global system, and actually inhibit local development as well. The expected consequence of this model is that local Fabs and the 6D Working Group will become more and more confident in their own actions, seeing the failure not as their own fault but as an attempt from the other part to counter them. "In general, at this stage, each partner has forgotten its original purpose in collaboration. It is much more aware of the things its partner has done to block it. This makes the partnership even more unlikely to talk, and it becomes even more unlikely that either side will ever learn the effect it is having on the other" (Senge, Ross, et al. 1994, p. 148).

In 1994, shortly after this archetype was discovered, Jennifer Kemeny proposed an action plan (Kemeny 1994) composed of seven points to counter the negative effects of this situation:

1. Reconstruct the conditions that were the catalyst for collaboration.

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[1] Quote from an interview with a tool owner

2. Review the original understandings and expected mutual benefits.
3. Identify conflicting incentives that may be driving adversarial behavior.
4. Map the unintended side effects of each party's actions.
5. Develop overarching goals that align the efforts of the parties.
6. Establish metrics to monitor collaborative behavior.
7. Establish routine communication.

This action plan emphasizes the need for a common vision in terms of results as well as processes. Each party has to articulate and share their needs and expectations so that both parties can understand and support each other. It may help in tempering reactions when breaches are perceived. Also, the plan draws the attention on team learning. "If the partners in the venture adopt a principle of continuous joint improvement and learning, the probability that breaches to the partnership will happen in the first place is diminished, as well as a higher probability that if and when misunderstandings, unrealistic expectations or performance problems do occur, the parties will have mechanisms in place to meet each other half way and work them out." (Braun 2002).

4.3.2 The adequate level of standardization

As for the discussion about compliance and accountability, the standardization tension may be solved by making a semantic distinction between processes and activities (or practices). Michael Hammer in *The Agenda* gives a precise definition of process: "an organized group of related activities that together create a result of value to customers." (Hammer 2001, p. 53). Two key concepts have to be highlighted: "together" and "value to customers." The way the process is set up must align every activity toward a common objective to deliver value to customers. In the previous section, we saw that the actual incentive scheme impeded this alignment. Solving this point may remove tension against standardization. Similarly, the 6D Working Group must be clear in what should be delivered to the customers. Some dimensions such as safety and reliability are obvious. However, if, for instance, historical data provided by the releasing site are essential for the receiving site, then this process has to be standardized in content, timing and way of transmission. Indeed, the author would argue that processes must be standardized while activities must be left to local practices. This assertion is based on a study made by Klein and Barrett (Klein and Barrett 2001). Figure 4-5 taken from this article emphasizes that when the outcomes of the processes must be identical then global processes have to be enforced by the 6D Working Group. This top-down approach may take the form of metrics, incentive or pure political power.

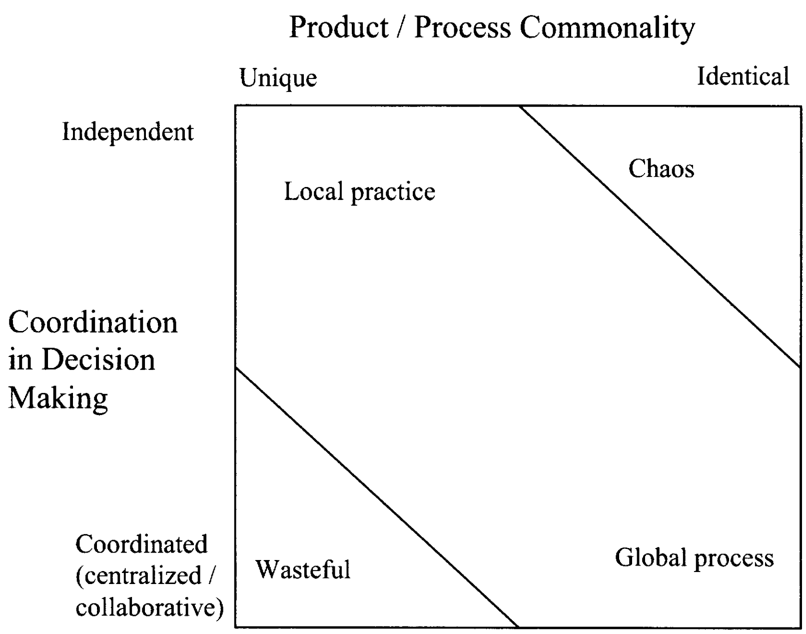


Figure 4-5: Local versus Global processes[1]

Consequently, the 6D Working Group should first determine the set of criteria that have to be identical to deliver value to the customers, and then enforce their standardization. For the 2D Checklists, we saw that standardizing all activity of the demolition created unfortunate tension between local sites and the 6D Working Group. However, it may be more appropriate to standardize the outcomes of these activities and leave the flexibility to the sites to decide how they deliver them. For instance, the Demo Safety Level 1 and 2 at the end of the 2D may be more specific for each type of tool.

Finally, one should not forget the competitive advantage Intel® has in reusing tools. This advantage is mainly achieved through good communication between sites and continuous

[1] From (Klein and Barrett 2001)

improvement (Beckman and Rosenfield 2008, p. 110). Therefore these two aspects have to be standardized. For communication between sites, the communication channels must be clear in terms of content, timing and way of transmission. It may be expected that with the proposed incentive scheme which makes the receiving site pay for tools it receives, the communication may improve. If not, it may have to be enforced by the management. As for continuous improvement, since process sharing is not "natural," it may be necessary to implement a set of metrics. The metric proposed in Section 4.2.3.3, "% TO providing 2 best practices at the end of the demolition" may drive the organization toward process sharing.

5 Conclusion

As highlighted throughout this thesis, implementing process changes in a global environment is not easy. Indeed, it requires understanding of the forces within and between local plants. During the six-month internship, the author saw these forces in action and tried to analyze them using academic tools such as three lenses analysis, game theory, and system dynamics models. In a certain way, it offered creative approaches based on strong theory and pragmatic experience; the *mens and manus* credo of MIT.

The recommendations and insights of this thesis can be summarized by the following three focus areas: drive accountability, improve communication between releasing and receiving sites, and foster standardization.

Lack of accountability can be seen in many areas. From an execution point of view, cannibalization is maybe the most relevant example. From a process point of view, the missing feedback certifications impede process improvement. To tackle these issues, the author created a new incentive policy in which the receiving site is required to pay for half of the fair market value of the tool. Also, most of the metrics proposed point out strategic objectives for which Fabs have to be accountable.

Communication between sites is key to capture the competitive advantage of reusing tools. As highlighted by the game theory analysis, significant value can be lost if each site acts on its own. The incentive policy may trigger this cooperation but some of the steps have to be enforced by top-management. Indeed, the 6D Program focuses on process design not execution. In many cases, this last piece is missing.

Finally, process improvement program such as Lean cannot be implemented without standardization. The main issue is to find the appropriate level, knowing that too focused standardization may drive unintended consequences. The solution to this dilemma may lay in the distinction between processes and activities. Processes delivering value to the customer have to be standardized while activities must be left to local practices. This assertion also links to two layers of Lean implementation: one at the global level and one at the local level.

Appendix A: Timeline of the Intel® processor introduction

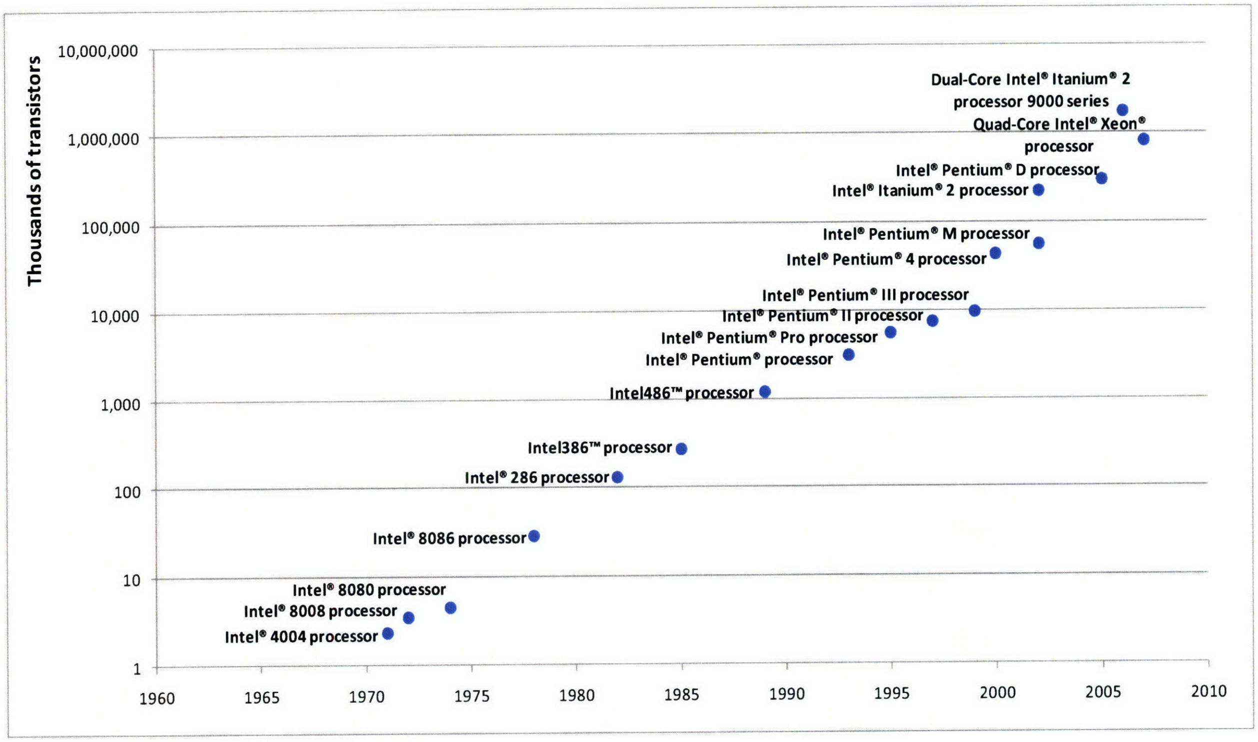


Figure A-1: Moore's law – Evolution of the number of transistors – Source: (Intel 2007)

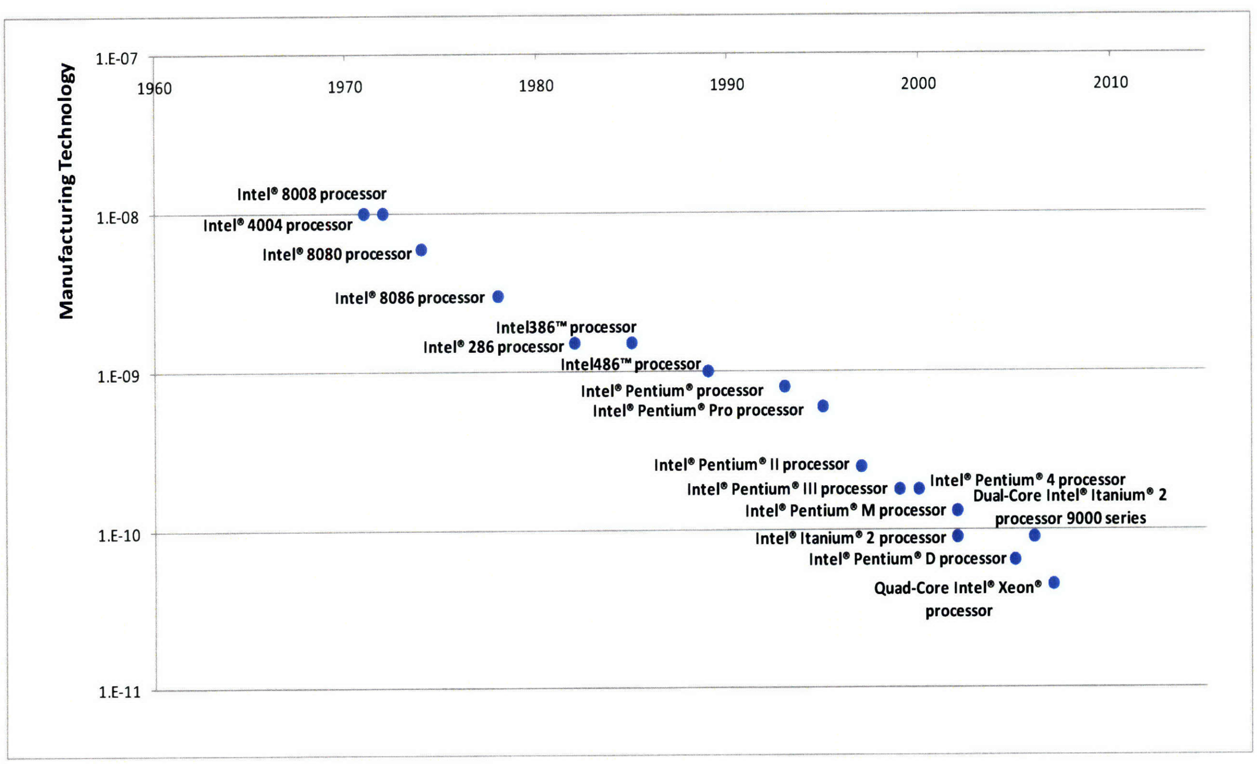
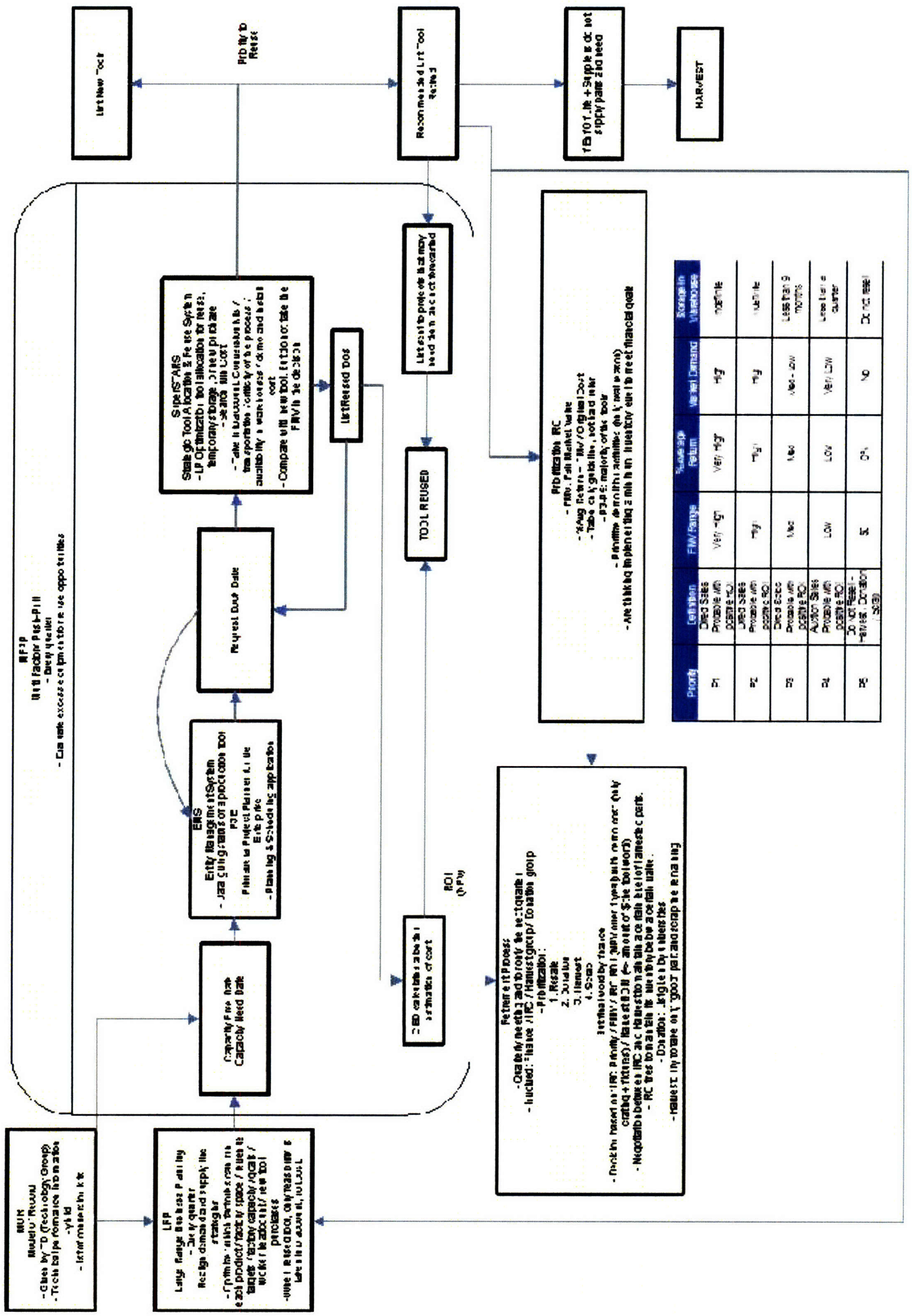


Figure A-2: Evolution of the manufacturing technology – Source: (Intel 2007)

Appendix B: Map of the tool allocation process



Appendix C: Results of a survey made in October 2007

Question 1:

What is your knowledge of the 6D Program?

1: No idea what the 6D Program is
2: Have heard about the 6D Program
3: Went to a general presentation
4: Follow the 6D Processes (2D Checklist, Standard Operating Procedures…)
5: Expert

Results: based on 103 surveys

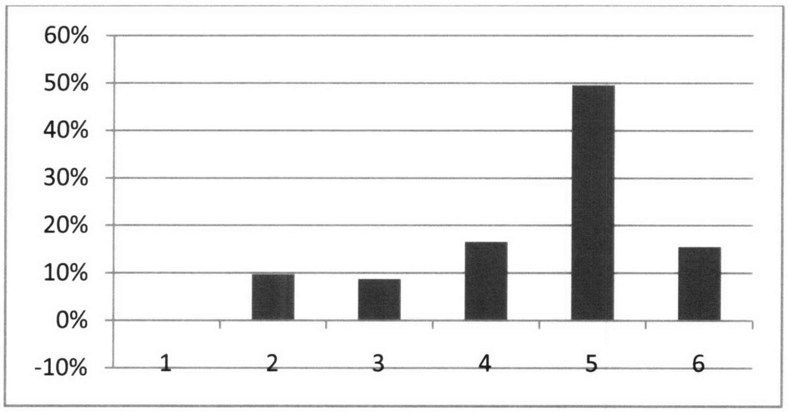


Figure C-5-1: Result Question 1

Question 2:

How do you assess a tool transfer event prior the creation of the 6D program?

1: Poor
2: Some efforts but far to be good
3: Average
4: Good but not best-of-class
5: Excellent

Results: based on 103 surveys

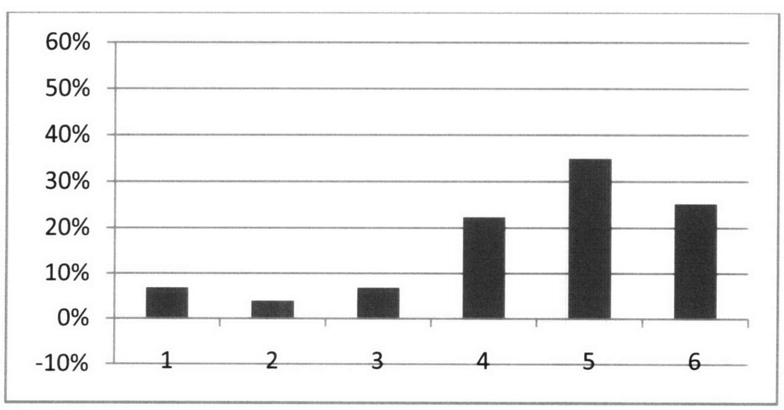


Figure C-5-2: Result Question 2

Question 3:

Rank by priority these objectives of a demolition event. From 1: high priority, to 5: low priority.

- ☐ Reliability of the tool when received
- ☐ On-time shipment / delivery
- ☐ Reduce rework (releasing and receiving site)
- ☐ Minimize cost of operations
- ☐ Safety
- ☐ Other not mentioned: ___________

Results: based on 89 surveys

Objectives \ Rank	1	2	3	4	5	Average ranking
Safety	93%	2%	2%	1%	1%	1.1
Reliability of the tool when received	6%	69%	12%	7%	7%	2.4
On-time shipment / Delivery	0%	9%	44%	26%	21%	3.6
Reduce rework	1%	9%	27%	31%	31%	3.8
Minimize cost of operations	0%	11%	15%	35%	39%	4.0

Question 4:

How do you assess a tool transfer event prior the creation of the 6D program?

0: N/A
1: Poor
2: Some efforts but far to be good
3: Average
4: Good but not best-of-class
5: Excellent

Amount of rework:
Cost:
On-time shipment / delivery:
Reliability of the tool when received:
Safety:

Results: based on 99 surveys

	0	1	2	3	4	5	**Average**
Safety	25%	10%	8%	7%	14%	35%	**3.74**
On-time shipment / delivery	30%	15%	9%	19%	18%	8%	**2.93**
Reliability of the tool when received	28%	8%	9%	14%	24%	16%	**3.43**
Amount of rework	41%	13%	13%	8%	19%	5%	**2.81**
Cost	32%	10%	26%	15%	10%	6%	**2.65**

* The average does not include the answer "0:N/A".

<u>Question 5:</u>

How do you assess a recent tool transfer event?

0: N/A
1: Poor
2: Some efforts but far to be good
3: Average
4: Good but not best-of-class
5: Excellent

Amount of rework:
Cost:
On-time shipment / delivery:
Reliability of the tool when received:
Safety:

Results for questions 4 and 5: based on 101 surveys

	Prior implementation of the 6D Program							**After the imlementation of the 6D Program**						
	0	1	2	3	4	5	**Average**	0	1	2	3	4	5	**Average**
Safety	24%	10%	5%	18%	17%	27%	**3.62**	24%	2%	3%	5%	11%	55%	**4.49**
On-time shipment / delivery	25%	5%	8%	26%	22%	15%	**3.45**	24%	2%	1%	19%	33%	21%	**3.92**
Reliability of the tool when received	25%	10%	21%	18%	15%	12%	**2.97**	28%	4%	7%	9%	28%	24%	**3.83**
Amount of rework	35%	12%	15%	22%	14%	3%	**2.71**	40%	6%	4%	13%	22%	14%	**3.58**
Cost	28%	8%	15%	31%	18%	1%	**2.85**	26%	7%	8%	23%	27%	9%	**3.30**

* The averages do not include the answer "0:N/A".

Question 6:

To what extent do you attribute these evolutions to the 6D Program?

0: N/A
1: Marginal (0% - 15%)
2: Some contribution (15% - 40%)
3: Half of the job (40% - 60%)
4: Significant contribution (60% - 85%)
5: Total (85% - 100%)

Amount of rework:
Cost:
On-time shipment / delivery:
Reliability of the tool when received:
Safety:

Results: based on 99 surveys

	0	1	2	3	4	5	**Average**
Safety	25%	10%	8%	7%	14%	35%	**3.74**
On-time shipment / delivery	30%	15%	9%	19%	18%	8%	**2.93**
Reliability of the tool when received	28%	8%	9%	14%	24%	16%	**3.43**
Amount of rework	41%	13%	13%	8%	19%	5%	**2.81**
Cost	32%	10%	26%	15%	10%	6%	**2.65**

* The average does not include the answer "0:N/A".

Question 7:

How do you see the role of the 6D Working Group? (Rank only 2 answers)

1. Analyst – Measure performance / metrics to assess a Fab and determined room for improvement.
2. Architect – Provide everything needed to manage the project: organizational structures, process, checklists…
3. Consultant – Provide suggestions that can be applied or not, depending of the situation.
4. Facilitator – Help in improving the processes by sharing best practices across Fabs.

    Best answer: ___
    2nd best answer: ___
    Other not mentioned: ____

Results:

Role \ Rank	1	2
Facilitator	34%	38%
Architect	33%	19%
Consultant	20%	33%
Analyst	12%	10%

90 surveys

Role \ Rank	1	2
Facilitator	30%	41%
Architect	51%	12%
Consultant	12%	34%
Analyst	7%	12%

Less mature sites (47 surveys)

Role \ Rank	1	2
Facilitator	38%	35%
Architect	17%	24%
Consultant	28%	33%
Analyst	17%	8%

Mature sites (43 surveys)

Question 8:

Rank by priority the actions the 6D Program should focus its effort. From 1: high priority, to 8: low priority.

- ☐ Drive Process Sharing
- ☐ Drive site accountability (metrics, financial impact…)
- ☐ Drive standardization of processes used across sites
- ☐ Drive standardization of team structure across sites
- ☐ Improve training
- ☐ Improve TRANS
- ☐ Push the use of TRANS
- ☐ Provide more specific and applicable processes
- ☐ Other not mentioned: ___________

Results: based on 83 surveys

Actions \ Rank	1	2	3	4	5	6	7	8	Average ranking
Standardization of processes	35%	30%	12%	4%	8%	5%	5%	1%	2.6
Drive accountability	22%	5%	18%	11%	18%	8%	6%	12%	4.1
Process Sharing	17%	17%	7%	20%	4%	13%	16%	6%	4.1
Improve training	8%	10%	18%	18%	16%	10%	12%	8%	4.4
Standardization of teams	5%	18%	13%	12%	13%	8%	8%	22%	4.8
Improve TRANS	5%	7%	11%	14%	16%	23%	16%	8%	5.0
Push TRANS	5%	7%	8%	10%	16%	16%	24%	14%	5.4
More specific and applicable processes	4%	6%	12%	12%	10%	17%	12%	28%	5.6

Appendix D: Equations related to the harvesting decision

This study is based on (Rosenfield 1989).

Assumptions:

- The demand for one type of part follows a Poisson process. In other words, the time, X, between two successive demands follows an exponential distribution. The probability density function with a rate parameter λ, average number of parts demanded per unit of time, is:

$$f(x,\lambda) = \begin{cases} \lambda e^{-\lambda x} & , x \geq 0 \\ 0 & , x < 0 \end{cases}$$

- The moment when the tool may be sold follow an exponential distribution. If μ represents the average number of tools expected to be sold per unit of time, then the probability density function is:

$$g(x,\mu) = \begin{cases} \mu e^{-\mu x} & , x \geq 0 \\ 0 & , x < 0 \end{cases}$$

- First-in First-out use of inventory of parts.

Notations:

μ : Average number of tools expected to be sold by unit of time. (unit: 1/year)

δ : Continuously compounded discount rate[1]. (unit: 1/year)

λ_i : Average number of parts of type i demanded by unit of time. (unit: 1/year)

A_i : Value of part of type i. (unit: $)

C_h : Total incremental cost of harvesting the tool. (unit: $)

C_s : Total incremental cost of selling the tool (crating, shipping fixtures…). (unit: $)

ENPV: Expected Net Present Value (unit: $)

$f_i(.)$: Probability density function of X_i.

g(.) : Probability density function of s.

---

[1] The annual discount rate is 15%. Therefore the annual continuous compounded discount rate is: $e^{-\delta} = \frac{1}{1+15\%}$.

$\delta = 14\%$

I_i : Number of parts of type i already in inventory.

N : Number of part types that can be harvested for the tool.

NPV: Net Present Value (unit: \$)

r_i : Cost per unit of time of space and other non-capital holding costs for the part of type i. (unit: \$/year)

s : Time when the tool is sold. (unit: year)

V : Sale value of the tool. (unit: \$)

$W_{i,j}$: Time when the j^{th} part of type i is used. (unit: year)

$X_i = W_{i,j+1} - W_{i,j}$: Time between the j^{th} and the $(j+1)^{th}$ demand of part of type i. (unit: year)

Conclusion

The tool must be harvested and not sold if and only if:

$$\boxed{\sum_{i=1}^{N}\left[\left(A_i+\frac{r_i}{\delta}\right)\left(\frac{\lambda_i}{\lambda_i+\delta}\right)^{I_i+1}-\frac{r_i}{\delta}\right]^{+}-C_h\geq\frac{V\mu}{\delta+\mu}-C_s}$$

The notation $[x]^+$ means only positive of x. $[x]^+ = Max[0;x]$.

Proof

- Expected net present value of selling a tool.

The net present value of selling the tool at time s is: $\text{NPV}_{\text{sale}} = Ve^{-\delta s} - C_s$

Therefore the expected net present value of selling the tool is:

$$\text{ENPV}_{\text{sale}} = E\left[Ve^{-\delta s}-C_s\right]=V\int_{s=0}^{+\infty}e^{-\delta s}g(s)ds-C_s=V\mu\int_{s=0}^{+\infty}e^{-(\delta+\mu)s}ds-C_s=V\mu\left[-\frac{e^{-(\delta+\mu)s}}{\delta+\mu}\right]_0^{+\infty}-C_s=\frac{V\mu}{\delta+\mu}-C_s$$

- Expected net present value of harvesting a tool,

The net present value of harvesting the tool is given by the expression:

$$\text{NPV}_{\text{harvest}} = -C_h+\sum_{i=1}^{N}\left(A_ie^{-\delta W_{i,I_i+1}}-\int_0^{W_{i,I_i+1}}r_ie^{-\delta t}dt\right)$$

With $A_i e^{-\delta W_{i,I_i-1}}$ is the present value of using the part of type i at the time W_{i,I_i+1}, and $\int_0^{W_{i,I_i+1}} r_i e^{-\delta t} dt$, the cost of inventory of this same part over the same period of time.

Indeed, if the inventory of parts of type i contains already I_i parts, then the time the part harvested will be used is W_{i,I_i+1} (First-In First-Out assumption). Also we take the sum over all the N parts of the tool that are considered to be harvested. We note that if the value of

$A_i e^{-\delta W_{i,I_i+1}} - \int_0^{W_{i,I_i+1}} r_i e^{-\delta t} dt$ is negative, keeping the part of type i in inventory is not cost effective.

Indeed, in this case, the cumulated cost of holding the part is higher than the value of the part.

Therefore the expected net present value of the first part of type i from harvesting the tool is:

$$\text{ENPV}_{\text{harvest}} = E\left[-C_h + \sum_{i=1}^{N}\left(A_i e^{-\delta W_{i,I_i+1}} - \int_0^{W_{i,I_i+1}} r_i e^{-\delta t} dt\right)^+\right] = -C_h + \sum_{i=1}^{N}\left(E\left[A_i e^{-\delta W_{i,I_i+1}}\right] - E\left[\int_0^{W_{i,I_i+1}} r_i e^{-\delta t} dt\right]\right)^+$$

- Calculation of the expected cost of inventory of the part harvested:

$$\int_0^{W_{i,I_i+1}} r_i e^{-\delta t} dt = r_i\left[-\frac{1}{\delta} e^{-\delta t}\right]_0^{W_{i,I_i+1}} = \frac{r_i}{\delta}\left(1 - e^{-\delta W_{i,I_i+1}}\right)$$

Then,

$$E\left[\int_0^{W_{i,I_i+1}} r_i e^{-\delta t} dt\right] = \frac{r_i}{\delta}\left(1 - E\left[e^{-\delta W_{i,I_i-1}}\right]\right)$$

- Calculation of $E\left[e^{-\delta W_{i,I_i+1}}\right]$

$$E\left[e^{-\delta W_{i,I_i+1}}\right] = E\left[e^{-\delta\left(W_{i,I_i} + X_i\right)}\right] = E\left[e^{-\delta W_{i,I_i}} e^{-\delta X_i}\right] = E\left[e^{-\delta W_{i,I_i}}\right] E\left[e^{-\delta X_i}\right]$$

- Proof per induction that $E\left[e^{-\delta W_{i,I_i+1}}\right] = \left\{E\left[e^{-\delta X_i}\right]\right\}^{I_i+1}$:

For $I_i = 0$, then $E\left[e^{-\delta W_{i,1}}\right]$ is the expected time of using one part of type i. Given the definition of X_i, $E\left[e^{-\delta W_{i,I1}}\right] = E\left[e^{-\delta X_i}\right]$.

We assume that H_{i+1}: $E\left[e^{-\delta W_{i,I_i+1}}\right] = \left\{E\left[e^{-\delta X_i}\right]\right\}^{I_i+1}$ is true.

$$E\left[e^{-\delta W_{i,I_i+2}}\right] = E\left[e^{-\delta\left(W_{i,I_i+1}+X_i\right)}\right] = E\left[e^{-\delta W_{i,I_i+1}}e^{-\delta X_i}\right] = E\left[e^{-\delta W_{i,I_i+1}}\right]E\left[e^{-\delta X_i}\right]$$
$$= \left\{E\left[e^{-\delta X_i}\right]\right\}^{I_i+1}E\left[e^{-\delta X_i}\right] = \left\{E\left[e^{-\delta X_i}\right]\right\}^{I_i+2}$$

Therefore, if H_{i+1} is true, then H_{i+2} is true.

- Calculation of $E\left[e^{-\delta X_i}\right]$

$$E\left[e^{-\delta X_i}\right] = \int_{x=0}^{+\infty} e^{-\delta x} f_i(x)dx = \int_{x=0}^{+\infty} \lambda_i e^{-\delta x} e^{-\lambda_i x}dx = \frac{\lambda_i}{\lambda_i+\delta}\left[-e^{-(\delta+\lambda_i)x}\right]_0^{+\infty} = \frac{\lambda_i}{\lambda_i+\delta}$$

Then, $E\left[e^{-\delta W_{i,I_i+1}}\right] = \left(\frac{\lambda_i}{\lambda_i+\delta}\right)^{I_i+1}$

- Final calculation of the expected net present value of harvesting the tool:

$$\text{ENPV}_{\text{harvest}} = -C_h + \sum_{i=1}^{N}\left(E\left[A_i e^{-\delta W_{i,I_i+1}}\right] - E\left[\int_0^{W_{i,I_i+1}} r_i e^{-\delta t}dt\right]\right)^+ = -C_h + \sum_{i=1}^{N}\left(A_i\left(\frac{\lambda_i}{\lambda_i+\delta}\right)^{I_i+1} - \frac{r_i}{\delta}\left(1-\left(\frac{\lambda_i}{\lambda_i+\delta}\right)^{I_i+1}\right)\right)^+$$

$$\text{ENPV}_{\text{harvest}} = -C_h + \sum_{i=1}^{N}\left(\left(A_i + \frac{r_i}{\delta}\right)\left(\frac{\lambda_i}{\lambda_i+\delta}\right)^{I_i+1} - \frac{r_i}{\delta}\right)^+$$

- Condition to harvest the tool:

The tool has to be harvested if and only if: $\text{ENPV}_{\text{harvest}} \geq \text{ENPV}_{\text{sale}}$.

$$\sum_{i=1}^{N}\left[\left(A_i + \frac{r_i}{\delta}\right)\left(\frac{\lambda_i}{\lambda_i+\delta}\right)^{I_i+1} - \frac{r_i}{\delta}\right]^+ - C_h \geq \frac{V\mu}{\delta+\mu} - C_s$$

Appendix E: Calculations in Section 3.2.4

Case 1: Model with neither bill back nor reward

Receiving Site Cooperation 1st phase		Releasing site Quality of desinstallation		Receiving site Quality of installation		Value Perceived	Costs demolition / installation	Additional Cost	Increase in value perceived	Total Releasing / Receiving	Total Intel
Cooperation	No Cooperation	Good	Cannibalization	Good	Poor						
x		x		x		0 / 700	-60 / -225	0 / 0	0 / 0	-60 / 475	415
x		x			x	0 / 650	-60 / -210	0 / 0	0 / 0	-60 / 440	380
x			x	x		120 / 350	-60 / -225	0 / -150	0 / 150	60 / 125	185
x			x		x	120 / 320	-60 / -210	0 / -130	0 / 130	60 / 110	170
	x	x		x		0 / 500	-60 / -215	0 / 0	0 / 0	-60 / 285	225
	x	x			x	0 / 450	-60 / -200	0 / 0	0 / 0	-60 / 250	190
	x		x	x		120 / 350	-60 / -215	0 / -150	0 / 150	60 / 135	195
	x		x		x	120 / 320	-60 / -200	0 / -130	0 / 130	60 / 120	180

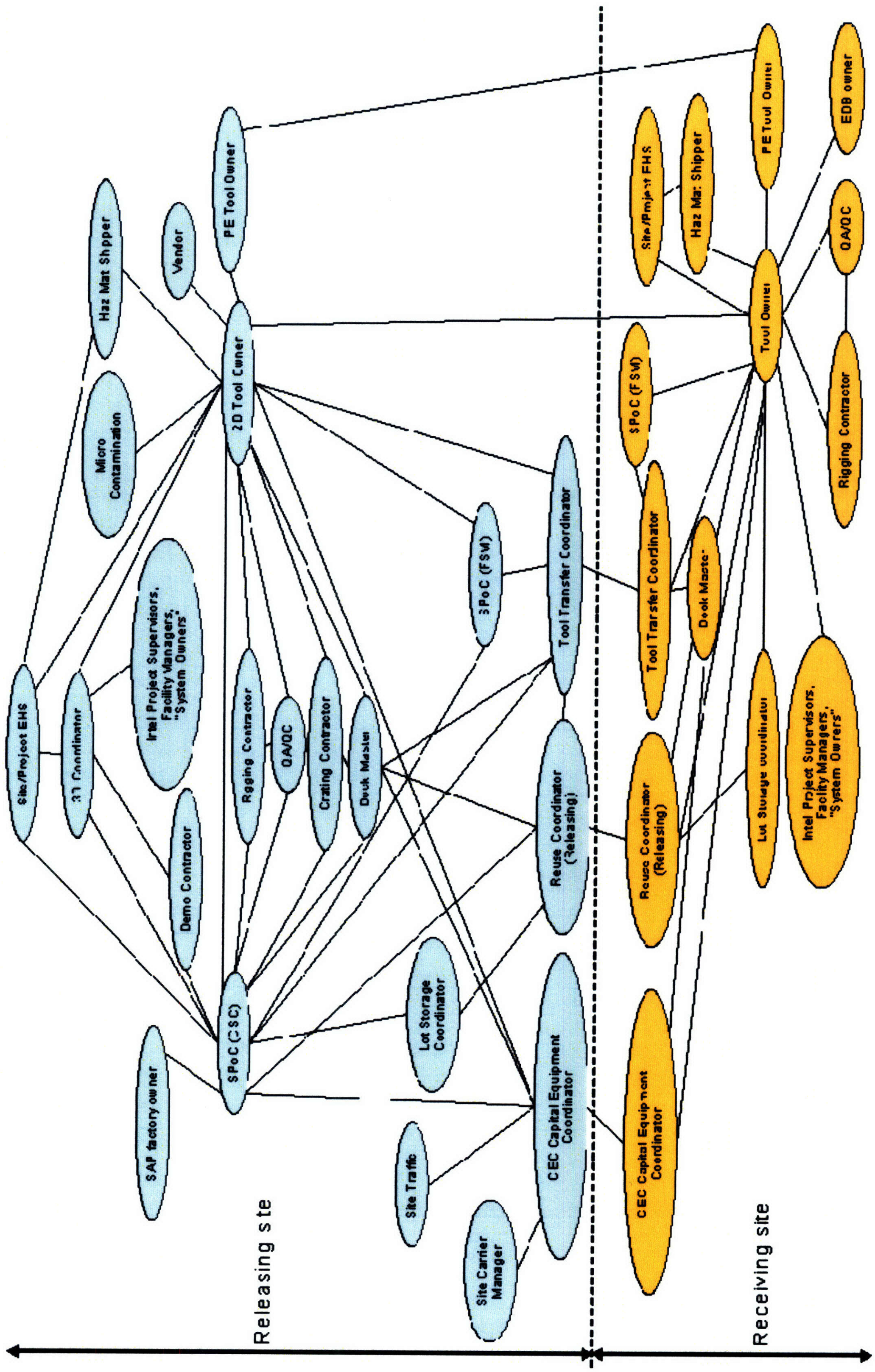
Case 2: Model with only bill-back

Receiving Site Cooperation 1st phase		Releasing site Quality of desinstallation		Receiving site Quality of installation		Value Perceived	Costs demolition / installation	Additional Cost	Increase in value perceived	Total Releasing / Receiving	Total Intel
Cooperation	No Cooperation	Good	Cannibalization	Good	Poor						
x		x		x		0 / 700	-60 / -225	0 / 0	0 / 0	-60 / 475	415
x		x			x	0 / 650	-60 / -210	0 / 0	0 / 0	-60 / 440	380
x			x	x		120 / 350	-60 / -225	-100 / -50	0 / 150	-40 / 225	185
x			x		x	120 / 320	-60 / -210	-100 / -30	0 / 130	-40 / 210	170
	x	x		x		0 / 500	-60 / -215	0 / 0	0 / 0	-60 / 285	225
	x	x			x	0 / 450	-60 / -200	0 / 0	0 / 0	-60 / 250	190
	x		x	x		120 / 350	-60 / -215	-100 / -50	0 / 150	-40 / 235	195
	x		x		x	120 / 320	-60 / -200	-100 / -30	0 / 130	-40 / 220	180

Case 3: Model with both bill-back and reward

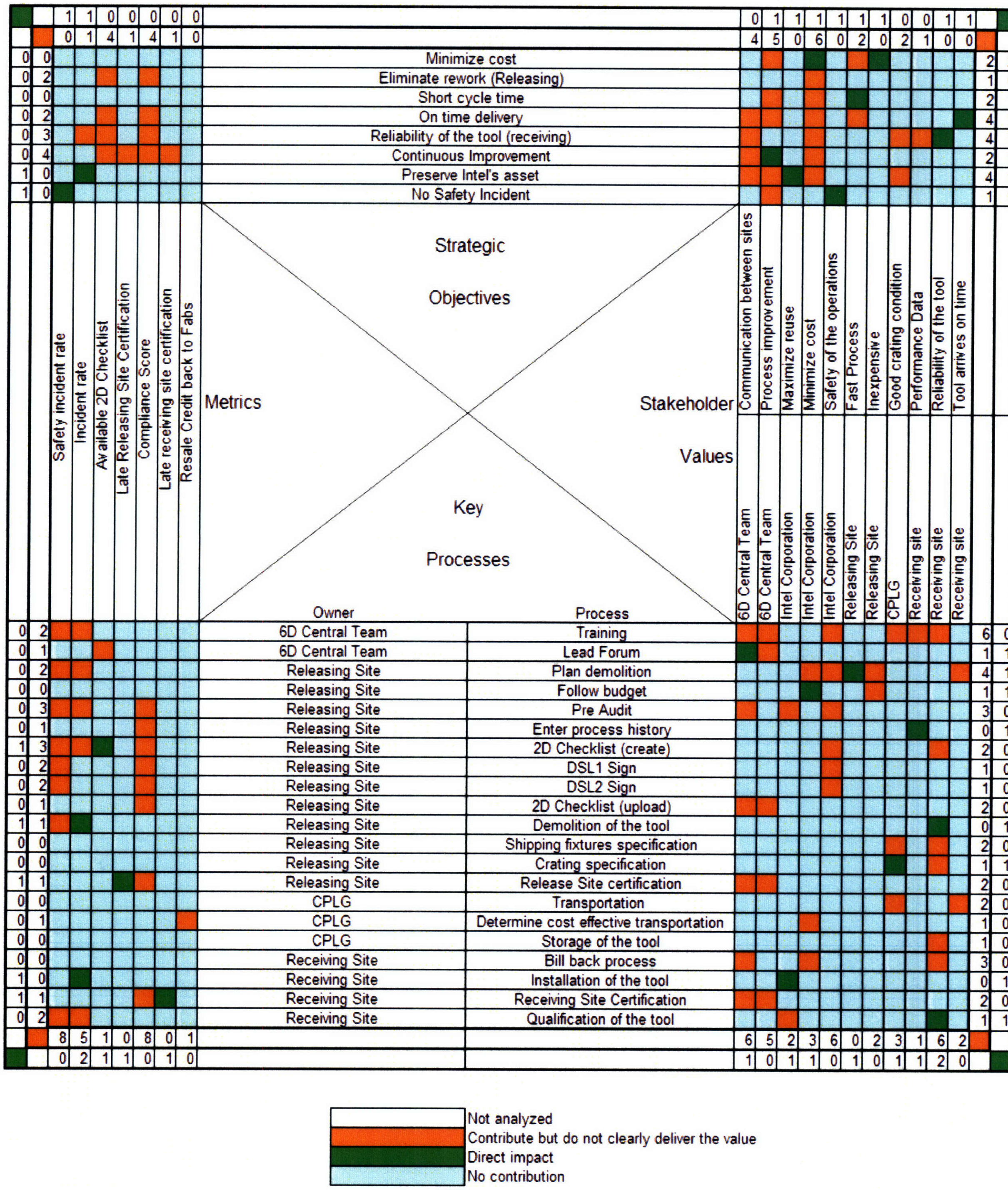
Receiving Site Cooperation 1st phase		Releasing site Quality of desinstallation		Receiving site Quality of installation		Value Perceived	Costs demolition / installation	Additional Cost	Increase in value perceived	Payment	Total Releasing / Receiving	Total Intel
Cooperation	No Cooperation	Good	Cannibalization	Good	Poor							
x		x		x		0 / 700	-60 / -225	0 / 0	0 / 0	250 / -250	190 / 225	415
x		x			x	0 / 650	-60 / -210	0 / 0	0 / 0	250 / -250	190 / 190	380
x			x	x		120 / 350	-60 / -225	-100 / -50	0 / 150	0 / 0	-40 / 225	185
x			x		x	120 / 320	-60 / -210	-100 / -30	0 / 130	250 / -250	210 / -40	170
	x	x		x		0 / 500	-60 / -215	0 / 0	0 / 0	250 / -250	190 / 35	225
	x	x			x	0 / 450	-60 / -200	0 / 0	0 / 0	250 / -250	190 / 0	190
	x		x	x		120 / 350	-60 / -215	-100 / -50	0 / 150	0 / 0	-40 / 235	195
	x		x		x	120 / 320	-60 / -200	-100 / -30	0 / 130	250 / -250	210 / -30	180

Appendix F: Interaction map



Metric	Formula
Safety incident rate	$= \dfrac{\text{\# Safety incidents by demolition start year}}{\text{\# of tools starting demolition by year}}$
Incident rate	$= \dfrac{\text{\#of incidents}}{\text{\# of Receiving Site Certifications received by demo year}}$
Available 2D Checklist	$= \dfrac{\text{\# of 2D Checklist created for tools starting demolition in next 90 days}}{\text{\# of tools starting demolition in next 90 days}}$
Late releasing site certification	$= \dfrac{\text{\#of uncertified transitions that have a Good Receipt Date}}{\text{\# of certified or uncertified transitions that have a Good Receipt Date}}$
Compliance score	Aggregate score by Fab of: • Pre Demolition Audit • Available 2D Checklist • Late releasing site certification • Late receiving site certification
Late receiving site certification	$= \dfrac{\text{\#of uncertified transitions that have an Intel Qualification Finish Date}}{\text{\# of certified or uncertified transitions that have an Intel Qualification Finish Date}}$
Resale credit back to Fabs	=YTD Credit from tool resale per Fab

Appendix H: X-Matrix[1]



[1] Source: (Nightingale and Stanke 2005)

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