The DNA of a High-Performing Manufacturing Organization: Improving Operations Capability through Performance Measurement

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Submitted to the Sloan School of Management and the Department of Chemical Engineering in Partial Fulfillment of the Requirements for the Degrees of

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and
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Abstract

The Broad Institute of MIT, Harvard, and the Whitehead Institute, contains the world’s highest-throughput genome sequencing center, which contributed approximately one third of the sequence for the Human Genome Project (HGP) completed in 2003. Broad’s Genome Sequencing Operations Group has acquired a cost leadership position within the genome sequencing industry through its competitive advantage in developing and implementing innovative, industrial-scale process technologies. Yet, this group has the opportunity to further improve its position as a leader in the genome sequencing industry by improving its operations capability to levels of world-class manufacturing organizations in other industries.

At the highest level, Broad’s management team sponsors Leaders for Manufacturing (LFM) internships as a long-term investment to improve the operations capability of its Genome Sequencing Group. Employees at Broad ultimately learn about leading-edge operations tools and principles through their exposure to LFM interns and their projects. While these investments have led to some significant operations improvements, the Genome Sequencing Group has not yet transformed into an organization that strives for operational excellence in the same way that world-class manufacturing organizations do. Thus, the primary goal of this thesis is to provide a methodology to transform the Genome Sequencing Group’s culture and catalyze the development of its operations capability.

Just as DNA contains the genetic instructions specifying the biological development of an organism, a performance measurement system contains the instructions that guide the development of an entire organization. Performance measurement systems provide the explicit incentive and accountability mechanisms necessary to motivate employees to achieve operational excellence. While training programs and exposure to leading-edge thinking are valid approaches to achieving operations improvements, these limited initiatives are simply not enough. The implementation of a performance measurement system at Broad would significantly enhance the results of Broad’s current approach to developing the operations capability of its workforce.

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1 Introduction

The Broad Institute was established in 2003 as a research collaboration between MIT, Harvard University and affiliated hospitals, and the Whitehead Institute for Biomedical Research. It is arguably the world’s premier genomic research organization, with an $80 million annual budget and approximately 250 employees. Most of the Broad’s funding comes in the form of research grants from the National Human Genome Research Institute, a division of the National Institutes of Health (NIH) in Washington D.C.\(^1\)

The Broad Institute houses five research platforms (platforms are teams of professional scientists that carry out major projects): Genome Sequencing, Genetic Analysis, Chemical Biology, Proteomics, and RNAi. These five platforms support eight high-level research programs focused on cell components, chemical biology, cancer genomics, metabolic diseases, psychiatric diseases, infectious diseases, bioinformatics, and medical and population genomics.\(^2\) The largest platform within the Broad Institute is Genome Sequencing. In the 1990s and early 2000s, when the current Genome Sequencing Platform was still part of the Whitehead Institute Center for Genomic Research, it gained worldwide recognition for contributing one third of the sequence for the Human Genome Project. Broad’s genome sequencing operation is the focus of this thesis as well as several previous LFM theses in 1999 through 2005.

The remainder of this chapter provides an introduction to Broad’s genome sequencing operations through a systems viewpoint and discusses the idea of system performance. The chapter concludes with a description of the motivation for the thesis project and the structure of the remaining chapters.

1.1 A Systems View of Broad’s Genome Sequencing Organization

Any organization, including Broad’s Genome Sequencing Operations Group, can be viewed as a black box that transforms inputs into outputs (see Figure 1 below). To evaluate and improve the performance of an organization, the input-output transformation that occurs within the representative black box must be examined in great detail.

\[\text{Inputs} \rightarrow \text{Organization} \rightarrow \text{Outputs}\]

*Figure 1. The Process View of an Organization.*

\(^1\) Source: Vokoun, Matthew, "Operations Capability Improvement of a Molecular Biology Laboratory in a High Throughput Genome Sequencing Center."

1.1.1 Broad's Genome Sequencing System Architecture

The transformation that occurs within an organization is defined by a system architecture that incorporates five elements: 1) Inputs and outputs; 2) A network of activities and buffers; 3) Resources; 4) Information structure; and 5) Process Management. See Figure 2 for a pictorial representation of Broad's state-of-the-art genome sequencing operation.

Inputs and outputs: Inputs refer to any tangible or intangible items that flow from the environment into the process, while outputs flow from the process back into the environment. In a typical manufacturing process raw materials and finished goods are the primary inputs and outputs. Within Broad's genome sequencing operation, the primary inputs are DNA samples from the organism chosen to be studied as well as raw materials for the various sequencing sub-processes, utilities such as electricity and water, and cash to pay for all of its activities. The primary output is genomic data that Broad publishes on public websites.

A network of activities and buffers: In a complex manufacturing operation, the input-output transformation occurs through multiple steps, or sub-processes. Broad's sequencing operation is broken up into four major sub-processes: Molecular Biology; Core Sequencing; Detection; and Finishing (which are described in further detail below). These sub-processes are ordered such that the output of one becomes the input to another. Adding further complexity, Broad's sequencing center is a multi-product operation in that the different organisms being sequenced may have unique processing requirements through each of the sub-processes. Finally, because work-in-progress must frequently wait in a queue between consecutive sub-processes, storage buffers of work-in-progress (inventory) of Broad's sequencing projects form.

Molecular Biology: DNA samples are usually provided to the Broad by scientists from external universities or research laboratories that specialize in extracting samples of DNA from the organism chosen to be studied. The first step performed within the Molecular Biology sub-process is DNA Preparation, which entails preparing purified DNA samples and then hydrodynamically shearing these samples to produce random small DNA fragments of an appropriate size range. The next step, Ligation, involves combining strands of DNA with known sequences (vectors) together with hydrodynamically sheared strands of DNA with unknown sequences (fragments). In this ligation step, both ends of a vector combine with both ends of a fragment to create a single, circular piece of DNA called a "plasmid." The final step within the Molecular Biology sub-process is Transformation. During the transformation step, plasmids are inserted into bacteria, such as E. coli, through a process called electroporation. After the introduction of plasmid, the competent bacteria cells are spread onto agar plates (plates that contain nutrients for the cells to grow as well as an antibiotic that selects only for cells with plasmid inserts) and allowed to grow into a large number of cell colonies in order to produce large amounts of replicated plasmids.

Core Sequencing: The first step performed within the Core Sequencing sub-process is Picking, where each individual cell colony from the transformation step is picked off of an agar plate by dedicated high-speed equipment into a single well of a 384-well plate. The second step, Templiphi, is a relatively new process that rapidly and efficiently produces

---

many copies of circular DNA. During the third step, *Big Dye*, the DNA clones are placed in a solution containing special DNA base pairs that are tagged with a fluorescent dye. When the temperature of the solution is raised, the plasmid double-stranded DNA separates into single strands, and when the temperature is lowered, an enzyme in the solution reconstructs the double-stranded structure by using base pairs from the surrounding solution. Whenever the enzyme grabs a dyed base pair from solution, the reconstruction process ends, leaving a DNA segment terminated with a dyed base. After many cycles, the result is a set of DNA fragments with dye-terminations at each base in the original DNA fragment sequence. The final step within the Core Sequencing sub-process is *Ethanol Precipitation* in which purified DNA strands are precipitated out from solution and re-suspended in a dilute EDTA solution.

**Detection:** In the detection sub-process, the dye-terminated segments from Core Sequencing are placed into sophisticated equipment referred to as “detectors.” In the detectors, the dyed plasmid segments are placed at one end of a long capillary where a charge causes the DNA to migrate through to the other end where a laser illuminates the dyed base pairs from each subsequent DNA strand. Smaller, lighter DNA segments move faster than larger, heavier segments, and a sensor detects the continuously varying illumination and records it in a data file. Software on the detector analyzes the illumination data to make a final determination of each base-pair in the sequence.

**Finishing:** This is the final major sub-process within Broad’s genome sequencing operation where highly skilled scientists analyze and fix any gaps within the final genome sequence. Gaps are areas of the sequence that are not determinable by the detectors which are closed by scientists through the utilization of a variety of laboratory techniques. Upon completion of this finishing sub-process, the final product, data representing a complete genome, is made publicly available on government websites.

**Resources:** Resources are tangible assets that are usually divided into two categories, capital and labor. Broad employs capital resources in the form of fixed assets such as the building and land it leases, equipment used in its various sequencing processes, and the information systems it uses to support its operations. Broad’s primary variable resource is its labor force of approximately 125 people which includes personnel such as managers, supervisors, operators, and technicians.

**Information Structure:** The information structure within an organization defines which information is available for managerial decision making. Managers at Broad have access to a wide variety of information through their frequent meetings with fellow employees and a number of information systems that can be utilized to ascertain quality, cost, or other important aspects of operational performance. Informational flow is represented in Figure 2 with dotted lines.

**Process Management:** The essence of process management is the policies that define how a system is operated over both short-term and long-term horizons. It is the primary responsibility of the managers at Broad to understand the ways that sequencing processes can be designed, redesigned, and managed to optimize organizational performance.
1.1.2 Defining System Performance

While the complexity of the system represented in Figure 2 does not lend itself to formal mathematical modeling, some general relationships can be defined. Specifically, the performance of the Broad’s genome sequencing operations can be defined as a function of the inputs and outputs, the design of the network of activities and buffers (design parameters), and the resources employed:

\[
\text{Performance} = F(\text{Inputs, Outputs, Design Parameters, Resources})
\]

It is possible to further decompose the performance function above into more descriptive variables. However, before proceeding with this step, consider the following four process attributes for measuring Broad’s ability to produce genomic data: cost, flow time, flexibility, and quality.\(^4\)

1. **Cost**: Represents the total cost that Broad incurs to generate genomic data. The total cost includes direct costs (such as raw materials, utilities, and labor) as well as capital (property and equipment), overhead costs, and money tied up in inventory.
2. **Flow time**: The flow time is the total time it takes for Broad to transform incoming DNA samples into genomic data.

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3. **Flexibility:** With respect to the Broad’s genome sequencing operation, process flexibility indicates the extent to which Broad is capable of meeting customer needs in generating genomic data for a range of organisms or projects.

4. **Quality:** The true quality of a sequencing process is fundamentally the accuracy of the genomic data it produces relative to the actual genome sequence. Because this accuracy is not directly measurable, objective and subjective judgments as well as perception play important roles in the estimation of a sequencing center’s process quality.

Based on the four important process attributes described above as well as a few generalizations and assumptions, Broad’s performance function defined in (1) can be modified to the following:

\[
    \text{Performance} = F \text{ (Direct Costs, Quality of Output, Quantity of Output, Waste, Flexibility, Flow Time, Inventory, Capital, Overhead Costs)}
\]

If each of the variables in (2) are treated as independent, performance is optimized through minimizing some variables (direct costs, waste, process flow time, inventory levels, money tied up in capital, and overhead costs) while maximizing others (quality of output, quantity of output, and process flexibility). However, the variables in (2) are clearly not independent. For example, the quantity of output from Broad’s genome sequencing operation will be negatively impacted if one of its bottleneck pieces of equipment, a detector, is sold off. Because all the explanatory variables in (2) are interdependent, calculating how to optimize the performance of this complex system is not a straightforward procedure.

Going back to the performance relationship defined in (1), optimality conditions, given a fixed set of resources, are obtained through adjusting the design parameters until the following condition is met:

\[
    \frac{d(\text{Performance})}{d(\text{Design\_Parameters})} = 0
\]

However, because the mathematical modeling relationships in (1) are unknown the optimality condition in (3) is not practically useful. Thus, given the lack of a theoretical or even empirical mathematical model, heuristic methods must be utilized to maximize operational performance.

In practice, organizations such as Broad’s Genome Sequencing Operations Group may attempt to maximize performance using the following rules of thumb:

- Pursue change initiatives that seek to improve one or more performance variables while leaving the other variables relatively unchanged.
- Scrutinize all change initiatives that promise to positively impact some performance variables but negatively impact others.
- In choosing which change initiatives to pursue, focus resources on those initiatives that are expected to generate the largest performance improvements relative to the money and effort required.
Following these rules of thumb is easier said than done. Effectively choosing which change initiatives to pursue in guiding an organization to constantly improve its performance is the essence of good management.

1.2 Project Motivation

By most accounts, the Broad’s Genome Sequencing Operations Group has established itself as the world’s best-performing large-scale genome sequencing organization. Its competitive advantage has been its ability to rapidly “industrialize” the genome sequencing process to improve its performance along the dimensions of flow time, flexibility, quality, and most notably, cost. In order to achieve these improvements Broad’s highly complex genome sequencing process is decomposed into many simpler sub-processes, enabling the organization to utilize high-volume process automation and information technology tools.

To complement its work design, the organization is divided into separate teams devoted to each of the sub-processes. The resulting organization consists of a layered reporting hierarchy of departments and sub-departments found in most traditional manufacturing plants and organizations. Effectively, the Broad Institute is the world’s premier DNA sequencing factory which constitutes one of the first applications of manufacturing-style management to a biotechnology process.5

Because Broad’s sequencing center operates similarly to a traditional manufacturing plant, the Genome Sequencing Operations Group has the opportunity to incorporate many of the proven management techniques that are used by world-class, high-performing manufacturing organizations. Although it may be the best-performing organization within its own industry, Broad stands to achieve much greater levels of performance through the utilization of selected performance improvement practices of other industry leaders.

Approaching ideal performance can be accomplished through two ways: radical reengineering and incremental continuous improvement. In either case, performance improvement requires investments in areas such as developing new technologies, equipment, workers’ skills, and suppliers’ capabilities. World-class firms operating at the performance frontiers of their respective industries maintain their competitive advantage relative to competition through the relentless pursuit of performance improvement.6

Throughout its existence, Broad’s Genome Sequencing Operations Group has achieved significant improvements in performance through relatively infrequent radical reengineering projects followed by frequent incremental continuous improvements. Just as in other industries where empirical evidence has shown that incremental improvements can be more economically significant than technologically spectacular improvements7, Broad has achieved the bulk of its improved results through an accumulation of several small gains.

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5 Source: Vokoun, Matthew, “Operations Capability Improvement of a Molecular Biology Laboratory in a High Throughput Genome Sequencing Center.”


7 Source: Rosenberg, N., “Inside the Black Box: Technology and Economics.”
Historically, the primary focus of Broad's performance improvement efforts has been to improve the processes and technologies that are directly related to genomic sequencing. Yet, as demonstrated during several recent LFM internships, efforts focused on improving the supporting operational activities can yield significant benefits as well (see section 10.3 for an example of one such project). Further, studies have shown that a large portion of productivity and performance improvements can take the form of an accumulation of small operational improvements driven by employees at all levels of the organization. In the opinion of the author, while Broad's Sequencing Group has clearly demonstrated its commitment to driving both radical and incremental improvements directly related to genome sequencing processes, the group has not demonstrated the same discipline and commitment to driving purely operational improvements.

An emphasis on continuous operational improvement is a central tenet of well-known Japanese management philosophies such as Lean and Total Quality Management (TQM). The application of these philosophies that emphasize 100% employee involvement in continuous improvement initiatives has played an important role in the success of many large Japanese organizations within the manufacturing sector. However, Broad's Sequencing Group has not traditionally involved all 100% of its employees in its own continuous improvement efforts. This is largely due to the high sensitivity of Broad's highly complex genome sequencing process to even small deviations in the processing environment. Thus, essentially all genome sequencing process changes are centrally managed and carefully coordinated to ensure the intended effects of the change are realized while unintended negative consequences do not result. Given the high level of knowledge required to adequately qualify process changes combined with the diversity of skill that exists within Broad's workforce, many lower skill employees are not involved in these types of improvement efforts.

One key challenge, then, for Broad's Genome Sequencing Group is to leverage the skills that each of its employees does possess and encourage everyone's involvement in continuous improvement efforts. One approach to this challenge is to continue to centrally control changes to the sequencing process environment, but to allow for decentralized control of improvement efforts focused on purely operational improvements. Many world-class manufacturing organizations manage change in a decentralized manner by organizing workers into teams, assigning a team lead who possesses certain prerequisite skills, and by allowing the team to validate and approve its own change proposals. High skill and low skill employees alike should be able to participate in operational improvement efforts.

Nevertheless, the two varieties of continuous improvement initiatives (process and operational) are not antithetical approaches. Both are valuable components to Broad's long-term performance improvement program. Thus, Broad's Genome Sequencing Operations Group stands to achieve more rapid improvement in its overall performance by further developing the capabilities of its entire workforce to lead and participate in both types of continuous improvement projects. Broad's management team is aware of this opportunity and is addressing it through sponsoring LFM internships and providing training in areas such as Six Sigma.

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8 Source: Fine, Charles H., and Evan L. Porteus, "Dynamic Process Improvement."
Ultimately, whether these training programs lead to real performance improvements remains to be seen. In the mind of the author, Broad’s training efforts will provide only insignificant benefits if corresponding incentive and accountability mechanisms for performance improvement are not established in parallel. This may particularly be the case with respect to encouraging purely operational improvements.. The author’s proposed solution is to implement a performance measurement system that establishes incentive and accountability mechanisms for performance improvements from employees at all levels and in all job functions. The vast majority of high-performing manufacturing organizations use performance metrics extensively to motivate and monitor their employees in the pursuit of performance improvements. Through training, Broad’s employees may learn various techniques that enhance their capabilities to improve the operational performance of the organization, but only through a cultural transformation will these employees truly embrace continuous operational improvement.

Figure 3 below is a system dynamics model that represents how a performance measurement system provides the motivation that is necessary to achieve a self-reinforcing continuous improvement loop within the workforce. Training alone does not create a self-reinforcing loop, but as Figure 3 indicates, training is still valuable because it does improve the success rate of performance improvement initiatives, which ultimately drives actual performance improvements.

![Figure 3. The Impact of Performance Measurement and Training on Performance.](image)

This thesis focuses on developing a methodology for initiating the transformation of Broad’s Genome Sequencing Operations Group into an organization that strives for operational excellence through the 100% participation of its employees in continuous improvement. At the heart of this transformation is the development of a performance measurement system that provides new incentive mechanisms and accountability of results for employees at Broad. In high-performing manufacturing organizations metrics are essential in providing an objective basis for decision-making as well as for providing incentive mechanisms and accountability for performance improvements. To improve the performance of an organization through both process and operations improvement initiatives, employees must have a good understanding of what their managers think is important and what metrics are being used to measure their contributions.
Beyond proposing a performance measurement system, an additional area of focus for the thesis is to address Broad’s opportunity to standardize and continuously improve some of its important business activities. Many of Broad’s business activities are currently managed in a manual, ad-hoc manner. Although there may be some tradeoff with respect to flexibility, one principle fervently followed by many world-class manufacturing organizations is that desired results are achieved more efficiently when activities are managed as a well-defined process. The key benefits of managing activities as a process include:

- Improved, consistent, and predictable results.
- Focused and prioritized improvement opportunities.
- Lower costs and shorter cycle times through effective use of resources.

Applying the principle of process approach typically leads to higher levels of performance through defining the activities that are necessary to obtain a desired result while allowing for the systematic elimination of non-value-adding activities. Examples of business activities that are typically standardized within high-performing manufacturing environments include: supplier performance reviews, inventory management policies, engineering changes, operator training, and employee performance reviews. This thesis focuses on some important business activities that are carried out by Broad’s Supply and Quality Management Group. These activities were objectively analyzed as processes and subsequently improved during the course of the author’s six and a half month internship.

1.3 Thesis Structure

The thesis proceeds as follows:

**Chapter 2, A Performance Measurement System for Broad** discusses the need for a performance measurement system within Broad’s Genome Sequencing Operations Group and provides an introduction to the Balanced Scorecard performance measurement system.

**Chapter 3, Creating Mission, Value, and Vision Statements** describes the first step in creating a Balanced Scorecard, which is formulating mission, value, and vision statements. These statements are the fundamental building block of the scorecard that is developed the subsequent chapters of this thesis.

**Chapter 4, Formulating a Strategy** describes the genome sequencing industry through a Porter’s Five Forces analysis and explains the optimal strategy for Broad’s Genome Sequencing Group given its position within the industry.

**Chapter 5, Choosing Performance Objectives** translates the strategy developed in chapter 4 into a set of explicit performance objectives that will ultimately be the basis for the measures chosen for Broad’s Balanced Scorecard.

**Chapter 6, Developing Measures, Targets, and Initiatives** explains how to choose appropriate measures and targets for a scorecard and proposes a set of measures for Broad’s Balanced

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Scorecard. The chapter concludes with a section describing how an organization’s change initiatives should link directly to the specific objectives and measures that make up its scorecard.

Chapter 7, Cascading the Balanced Scorecard proposes scorecard measures for three sub-groups within the larger Genome Sequencing Operations Group. Cascading refers to the process of developing Balanced Scorecards at every level of the organization by which the scorecards constructed at lower levels should align with the highest-level scorecard.

Chapter 8, Implementing a Balanced Scorecard at Broad describes a strategy for successfully implementing a Balanced Scorecard performance measurement system at Broad.

Chapter 9, Materials Change Management System discusses a materials change management process that was designed and implemented during the course of the six and a half month LFM internship. The chapter concludes with a section devoted to evaluating a proposed change to an important and expensive reagent used in Broad’s genome sequencing process.

Chapter 10, Materials Delivery, Quality Management, and Inventory Policies examines initiatives undertaken to improve a selection of the Supply and Quality Management Group’s important business processes. This chapter communicates the results of work completed to date and includes the author’s recommendations for continued work to further improve these processes.

Chapter 11, Conclusions ties the discussion of the preceding chapters together and offers some perspectives on how performance measurement and the principle of process approach can help improve Broad’s operations capability.
2 A Performance Measurement System for Broad

This chapter highlights the need for a performance measurement system at Broad and highlights the expected benefits of implementing such a system. An introduction to the specific performance measurement framework chosen for Broad’s Genome Sequencing Group, the Balanced Scorecard, is provided, and the objectives and five necessary steps for creating and implementing a scorecard are discussed.

2.1 Why Does Broad Need a Performance Measurement System?

Historically, the Broad Institute’s Genome Sequencing Organization has achieved significant performance improvements through infrequent radical innovations in high-throughput genome sequencing technologies followed up by lots of incremental improvements. The effect of these initiatives has been a drastic reduction in the cost to sequence a mammalian genome (see Figure 4) leading to some comparisons to efficiency gains seen in the microprocessor industry based on Moore’s Law. While the reductions in sequencing production costs have been tremendous, Broad stands to achieve even greater results through leveraging selected management techniques of world-class manufacturing organizations in other industries. One such technique is the utilization of a performance measurement system – a measurement system that would provide better motivation and alignment for employees at Broad to effectively develop the operations capability of the organization to ultimately achieve higher levels of performance.

![Cost of a Mammalian Genome](image)

Figure 4. Actual and Projected Efficiency Gains in Genome Sequencing Production.\(^\text{10}\)

\(^{10}\)Source: Presentation at The Broad Institute, July 2004
An organization’s measurement system strongly affects the behavior of people inside the organization. As the saying goes, “If you can’t measure it, you can’t manage it.” Broad’s Genome Sequencing Operations Group has traditionally relied upon a small set of high-level metrics that do not serve to guide the everyday actions of a typical Broad employee. If the Sequencing Group is to develop a high-achieving and performance-driven culture necessary to maintain its leadership position in the genome sequencing industry, then this group must use better performance measurement and management systems that will effectively motivate employees to drive significant operations improvements.

The metrics utilized by an organization should fulfill the fundamental activities of measuring (evaluating what the organization is doing), educating (since what’s measured is important; what is measured indicates how the organization intends to deliver value to its customers), and directing (potential problems are flagged by the size of the gaps between the metrics and the standard). There is an oft-repeated maxim in manufacturing that states, “You get what you inspect, not what you expect.”

Choosing the right performance measurement system for a given organization can become an arduous task as there are countless varieties of performance measurement systems being utilized by organizations around the globe. One of the more well-known systems, the Balanced Scorecard, has found widespread applicability in the both the for-profit and not-for-profit sectors and was therefore chosen by the author as the proposed performance measurement system for Broad.

### 2.2 Benefits of a Balanced Scorecard at Broad

Beyond providing accountability and incentive mechanisms for Broad’s employees, the Balanced Scorecard gives managers a comprehensive framework that helps translate the Genome Sequencing Group’s mission, vision, and strategy into a coherent set of performance measures that can be easily communicated to employees throughout the organization. Metrics and performance measurements are critical elements in translating an organization’s mission, vision, and strategy into reality. Metrics without strategy is meaningless and strategy without metrics is useless. Ultimately, Broad’s Sequencing Group will achieve the highest levels of performance improvement through the design and implementation of a performance measurement system that emphasizes improvements that are of strategic importance.

Many organizations, including the Broad Institute, have long adopted mission statements to communicate fundamental values and beliefs to all employees. The Broad Institute has the following stated mission:

- **Our scientific mission is:**
  - To create tools for genomics medicine and make them broadly available to the scientific community.
  - To apply these tools to propel the understanding and treatment of disease.

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12 Source: Melnyk, Steven A., et. al. “Metrics and performance measurement in operations management: dealing with the metrics maze.”
Our organizational mission is:
  - To enable collaborative projects that cannot be accomplished solely within the traditional setting of individual laboratories.
  - To empower scientists through access to cutting-edge tools.

While this stated mission may be inspirational for the Broad Institute as a whole, it is certainly not sufficient for guiding the everyday activities of individuals within Broad’s Genome Sequencing Operations Group. As Peter Senge (Senior Lecturer at the MIT Sloan School of Management) observed: “Many leaders have personal visions that never get translated into shared visions that galvanize an organization. What has been lacking is a discipline for translating individual vision into shared vision.”

A Balanced Scorecard measurement system would allow the Genome Sequencing Group to articulate its strategy, to communicate its strategy to its employees, and to help align individual, organizational, and cross-department initiatives to achieve more dramatic performance improvements. According to Robert Kaplan (originator of the Balanced Scorecard), the four perspectives of the scorecard (customer, internal processes, employee learning and growth, and financial) “... permit a balance between short-term and long-term objectives, between outcomes desired and the performance drivers of those outcomes, and between hard objective measures and softer, more subjective measures.” Properly constructed scorecards contain a unity of purpose with all the measures directed toward achieving an integrated strategy.

Although the Balanced Scorecard framework was originally conceived with the for-profit world in mind, some public and nonprofit agencies that were early adopters of the framework were able to adapt it, with success, to their own unique circumstances. For example, the City of Charlotte, North Carolina, implemented the Balanced Scorecard in 1996. Among the benefits cited are:

- Awareness and understanding of strategy.
- Linkage of budgets and strategy.
- Enhanced consensus and teamwork throughout the organization.
- Improved management decision making.
- Ability to report outcomes to the community.

It is the opinion of this author that the Broad Institute’s Genome Sequencing Group would significantly benefit from a 1) well-designed and 2) well-implemented performance management system. The purpose for writing chapters 2 through 7 is to overcome the first challenge: to design a well-designed performance management system. Chapter 8 will outline some recommendations for implementing the Balanced Scorecard at Broad. It will ultimately be the responsibility of management at Broad to take on the challenge of actually implementing it – or, better yet, assigning the implementation project to a new Leaders for Manufacturing Intern!

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2.3 Introduction to the Balanced Scorecard

In the early 1990s, Robert Kaplan (Professor at the Harvard Business School) and David Norton (President of Renaissance Solutions, Inc., an international consulting firm specializing in performance measurement) sought to solve a performance measurement problem affecting corporations throughout the world. Strategy was (and still is) considered a powerful defense for succeeding in the new global economy. However, the facts indicated that roughly 90 percent of organizations were unable to execute their own strategies.17

Kaplan and Norton identified that the performance measurement systems utilized by most firms were not capable of providing the information needed in the rapidly changing world of business. Most measurement systems were remarkably unchanged from those developed by the industrial giants in the early 1900s. These antiquated measurement systems were characterized by a nearly exclusive reliance on financial measures of performance and were not helpful in preparing modern organizations for their most important challenges.17

Kaplan and Norton believed that organizations would significantly benefit by introducing balance to their performance measurement systems. More specifically, the financial measures must be balanced with the drivers of future financial performance in an attempt to better execute strategy. Their approach was called the Balanced Scorecard, and featured four distinct, yet interrelated areas: customer, internal processes, employee learning and growth, and financial.17

Since the introduction of the Balanced Scorecard in the 1990s, it has been embraced by corporations around the world. A 2003 estimate suggests at least 50 percent of Fortune 1000 organizations use a Balanced Scorecard system.17 Like the instrumentation a pilot relies on in a jet airplane, the Balanced Scorecard provides managers in these Fortune 1000 organizations with the instrumentation they need to navigate to future competitive success. The Balanced Scorecard translates an organization’s mission, vision, and strategy into a comprehensive set of performance measures that provides the framework for a strategic measurement and management system.18

2.3.1 The Primary Objectives for Implementing a Balanced Scorecard at Broad

Even the most well-conceived and skillfully constructed Balanced Scorecard will not instantly transform an organization. To harness the benefits of any performance measurement and management system, the management team of an organization must understand why a system is needed in the first place.18 For the Broad’s Genome Sequencing Group, the objectives for implementing a Balanced Scorecard are the following:

- Provide a catalyst for the further development of operations capability.
- Align employee efforts to strategic goals.
- Fully engage all employees and motivate them to achieve performance improvements.

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A widely understood rationale for the Balanced Scorecard is critically important such that an organization does not lose sight of the purpose for measuring performance. The four objectives listed above are drivers for transforming the Broad’s Genome Sequencing Group into a performance-driven and high-achieving organization.

### 2.3.2 The Five Steps to Designing a Balanced Scorecard

Now that the need for a performance measurement system has been determined, the Balanced Scorecard has been introduced, and the primary objectives for implementing a scorecard have been identified, it is time to design a Balanced Scorecard for Broad’s Genome Sequencing Group. The five core steps involved in designing a Balanced Scorecard are:

1. Creating mission, value, and vision statements.
2. Formulating a strategy.
3. Choosing performance objectives for the scorecard.
4. Developing measures, targets, and initiatives for the scorecard.
5. Cascading the Balanced Scorecard to every level of the organization.

Chapters 3 through 7 cover each of these five steps in detail. Chapter 8 serves as a guide for the actual implementation of a Balanced Scorecard at Broad.
3 Creating Mission, Value, and Vision Statements

Performance measurement and management systems are devices that companies can use to implement and pursue their strategies. But prior to even formulating strategy, it is critically important for a company to contemplate its own mission, values, and vision. This chapter describes how to go about developing these fundamental building blocks, and include some draft mission and vision statements for the Broad’s Genome Sequencing Group (the author does not intend to create final mission and vision statements, as the process for creating these should include significant input from managers and employees at Broad).

3.1 Mission

The purpose of a company’s mission statement is to answer the following questions: 1) Who are you as an organization? 2) Whom do you serve? 3) Why do you exist? The mission should also reflect employees’ motivation for engaging in the organization’s work. Researchers for the Independent Sector found that, “a clear, agreed-upon mission statement is one of the four primary characteristics of successful non-profit organizations.” The following attributes make for the most effective and enduring mission statements:

- Simple and clear.
- Inspire change.
- Long-term in nature.
- Easy to understand and communicate.

Based on these desired attributes and the mission for the Broad Institute as a whole, the following draft mission statement was developed for Broad’s Genome Sequencing Group:

“Our mission is to make large-scale genome sequencing data broadly available to the scientific community to enable research that advances genomics medicine and propels the understanding and treatment of disease.”

3.2 Values

Values are timeless principles that guide an organization. They represent the deeply held beliefs within the organization and are demonstrated through the day-to-day behaviors of all employees. An organization’s values make an open proclamation about how it expects everyone to behave – and these values should be authentic and unique to that organization. While practices, processes, and strategies should change over time in answer to the many new challenges that inevitably emerge, an organization’s values should remain the same.

Here are two examples of companies with authentic and unique stated values:

*Amazon.com’s core values:*\(^{22}\)

- **Customer Obsession:** We start with the customer and work backwards.
- **Innovation:** If you don't listen to your customers you will fail. But if you only listen to your customers you will also fail.
- **Bias for Action:** We live in a time of unheralded revolution and insurmountable opportunity – provided we make every minute count.
- **Ownership:** Ownership matters when you're building a great company. Owners think long-term, plead passionately for their projects and ideas, and are empowered to respectfully challenge decisions.
- **High Hiring Bar:** When making a hiring decision we ask ourselves: "Will I admire this person? Will I learn from this person? Is this person a superstar?"
- **Frugality:** We spend money on things that really matter and believe that frugality breeds resourcefulness, self-sufficiency, and invention!

* Dell’s values (“The Soul of Dell”):\(^{23}\)

- Customers: We believe in creating loyal customers by providing a superior experience at a great value. We are committed to direct relationships, providing the best products and services based on standards-based technology, and outperforming the competition with value and a superior customer experience.
- The Dell Team: We believe our continued success lies in teamwork and the opportunity each team member has to learn, develop and grow. We are committed to being a meritocracy, and to developing, retaining and attracting the best people, reflective of our worldwide marketplace.
- Direct Relationships: We believe in being direct in all we do. We are committed to behaving ethically; responding to customer needs in a timely and reasonable manner; fostering open communications and building effective relationships with customers, partners, suppliers and each other; and operating without inefficient hierarchy and bureaucracy.
- Global Citizenship: We believe in participating responsibly in the global marketplace. We are committed to understanding and respecting the laws, values and cultures wherever we do business; profitably growing in all markets; promoting a healthy business climate globally; and contributing positively in every community we call home, both personally and organizationally.
- Winning: We have a passion for winning in everything we do. We are committed to operational excellence, superior customer experience, leading in the global markets we serve, being known as a great company and great place to work, and providing superior shareholder value over time.

The deeply held values of an organization and underlying culture can provide a significant and sustainable competitive advantage. The cultures that exist within companies such as Amazon.com and Dell have been key drivers to these companies’ successes in highly competitive industries. While Amazon.com and Dell have explicitly stated their corporate values,


every organization has a set of values that are demonstrated everyday. The Broad Institute’s Genome Sequencing Group is no exception. The question for this group is: do its values represent a competitive advantage within the genome sequencing industry? If the answer to the question is no, then the key to changing these values lies in open and honest identification of the current value systems that exist and are rewarded in the organization.

By providing the above examples of Amazon.com’s and Dell’s values statements, it is not the intention of the author to prescribe these or other values for Broad. To the contrary, it is the opinion of this author that the process of creating values should be conducted internally by managers within Broad’s Genome Sequencing Group. To this end, the author does not even go so far as to suggest a draft values statement here. Nonetheless, managers at Broad should not feel compelled to involve the entire employee body in the creation of its values. An organization’s values should support that organization’s mission and objectives. However, it is important that Broad’s managers ensure that there is alignment to these values throughout the Genome Sequencing Group such that all employees can see how their day-to-day actions are consistent with the values of their organization.

### 3.3 Vision

A vision statement provides a picture, in words, of what an organization ultimately intends to become. This vision of the future may be 5, 10, or even 15 years into the future. A powerful vision provides everyone in the organization with a shared mental framework that helps give form to the abstract future that lies ahead. An effective vision statement has the following characteristics:

- Is concise.
- Balances external and internal elements.
- Appeals to all stakeholders.
- Is consistent with mission and values.
- Is verifiable.
- Is feasible.
- Is inspirational.

It is important to note that while an organization’s mission and values statements should typically not change, the vision for an organization may require periodic modifications. Based on the desired characteristics of a vision statement along with the National Institutes of Health’s vision to cut the cost of whole-genome sequencing to $1,000 or less, the following draft vision was developed for Broad’s Genome Sequencing Group:

“Our vision is that we will lead the way to sequencing an entire human genome for $1,000 or less, which will enable the sequencing of individual genomes as part of routine medical care.”

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4 Formulating a Strategy

The uplifting words of mission, values, and vision statements represent nothing but wishful thinking if they are not accompanied with a strategy. The lofty aims declared in the mission, values, and vision statements answer the questions "why" and "who", the intention of formulating a strategy is to answer the question "how". But even a good strategy is not enough to transform an organization; only through execution of that strategy will significant results be achieved. Nevertheless, formulating an explicit strategy is an essential step in developing a Balanced Scorecard, and this chapter is devoted to that cause.

The first step in formulating a strategy for Broad's Genome Sequencing Group is to understand the industry in which they compete. This is accomplished through a Porter's Five Forces analysis (an analytical method developed by Professor Michael Porter of the Harvard Business School) that considers 1) Barriers to entry; 2) Buyer power; 3) Supplier power; 4) Threat of substitutes; and 5) Rivalry. Following this industry analysis an optimal strategy is chosen to allow the Genome Sequencing Group to achieve its mission and vision.

4.1 Barriers to Entry / Threat of Entry

Competition in an industry is not limited to the rivalry that exists among incumbent firms; the possibility that new firms may also enter the industry affects the competitive environment as well. In pure economic theory, a firm should be able to freely enter and exit a market and profits should always be nominal. In reality, however, incumbent firms in profitable industries inhibit new firms from entering the market to protect their high profit levels. These are barriers to entry.27

Focusing on the segment of the genome sequencing industry which competes for public funds, several barriers to entry exist. These primary barriers take the form of favorable relationships with customers, proprietary knowledge and know-how, asset specificity inherent to the industry, and the lack of evidence that this industry provides large-scale commercial value. Each of these barriers will be described in some detail below.

4.1.1 Relationships with Customers

Two of the major customers for large-scale sequencing data that provide public funding to genome sequencing centers are the National Human Genome Research Institute (NHGRI) and the Department of Energy (DOE). Although the role of these two government entities is not to regulate the genome sequencing industry, these organizations are interested in maintaining a portfolio of sequencing centers that are capable of meeting the need for reliable, high-quality genomic data. Established centers, such as the one that exists at Broad, have demonstrated their capabilities along this dimension and have developed good reputations among the people at the NHGRI and DOE who allocate annual or project-based grants. Quality of data is extremely important in the sequencing industry, and the long history of reliable data produced by established centers would tend to inhibit significant portions of public funding from being

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27 Source: Porter, Michael E., “Competitive Strategy.”
allocated to new, unestablished firms. This potentially creates a significant barrier to entry that is advantageous to the established sequencing centers.

A third sizable customer for large-scale sequencing data is the Wellcome Trust in England, which is an independent charity that has provided genome sequencing funds exclusively to the Sanger Institute, also located in England. In this relationship, the Sanger Institute clearly benefits from a lack of direct competition for significant public funding.

4.1.2 Proprietary Knowledge

The knowledge associated with setting up and running a genome sequencing center is not trivial. The biological processes are complex, the information technology systems are elaborate, and the learning curve associated with this industry has been fairly steep. On the other hand, a great deal of state-of-the-art knowledge is common and widely known throughout the industry – and can likely be acquired with enough effort or money. Clearly, not just anybody could overcome the technological barriers required to start up a genome sequencing center. However, firms in the biopharma industry do possess all the appropriate capabilities, and several of them have already established their own internal small- to medium-sized sequencing centers.

4.1.3 Asset Specificity

The largest capital expenditure in all genome sequencing centers is the DNA sequence detectors. Each one of these detectors costs in excess of $300K, and there are tens and even hundreds of these running at each of the major sequencing centers. Further, these detectors are highly specific to the genome sequencing industry and have no value in other industries. Because the genome sequencing industry requires highly specialized and expensive equipment, potential entrants are reluctant to enter because acquiring highly specialized assets that cannot be sold or converted for other uses is a risky venture. Additionally, when firms already hold industry-specific assets they fiercely resist efforts by others from taking their market share – and this fierce resistance is typically anticipated by potential new entrants.

4.1.4 Lack of Commercial Value

The genome sequencing industry has undergone an incredible cycle of boom, bust, and then stabilization over the last 10-15 years, primarily fueled by the excitement and anticipation of the completion of the Human Genome Project. While there is still optimism regarding the benefit and success of genomics, the success of genomics in financial markets and public funding arenas has not yet been clearly established.\(^{28}\)

Since most publicly-funded genome sequencing projects produce large datasets that are used in biomedical research on therapies that won’t hit the market for 10-20 years, the near-term economic value is lacking to fuel large sources of demand from private industry. Thus, the government and charitable organizations are needed to step in and fund this longer-range research. This funding is given out in large annual or project-specific grants that genome sequencing centers compete with each other for primarily based on cost and quality.\(^{28}\) The

\(^{28}\) Source: Vokoun, Matthew, “Operations Capability Improvement of a Molecular Biology Laboratory in a High Throughput Genome Sequencing Center.”
majority of publicly-funded sequencing centers operate on a not-for-profit basis, which means that private centers have to perform the same activities at a sufficiently low cost relative to public centers if they intend to make even a modest profit. Thus, the genome sequencing industry does not provide overwhelming economic incentives to attract significant investment by private firms.

4.2 Buyer Power

The relative power of buyers can significantly affect the attractiveness of an industry. In general, when buyer power is strong, the relationship with the producers is near to what an economist terms a monopsony—a market in which there are many suppliers and one buyer. Under such market conditions, the buyer sets the price. In reality, few pure monopsonies exist, but frequently there is some asymmetry between buyers and producers. The following table outlines some factors that determine buyer power.29

<table>
<thead>
<tr>
<th>Buyers are Powerful if:</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buyers are concentrated - there are a few buyers with significant market share</td>
<td>DOD purchases from defense contractors</td>
</tr>
<tr>
<td>Buyers purchase a significant proportion of output - distribution of purchases or if the product is standardized</td>
<td>Circuit City and Sears' large retail market provides power over appliance manufacturers</td>
</tr>
<tr>
<td>Buyers possess a credible backward integration threat - can threaten to buy producing firm or rival</td>
<td>Large auto manufacturers' purchases of tires</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Buyers are Weak if:</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Producers threaten forward integration - producer can take over own distribution/retailing</td>
<td>Movie-producing companies have integrated forward to acquire theaters</td>
</tr>
<tr>
<td>Significant buyer switching costs - products not standardized and buyer cannot easily switch to another product</td>
<td>IBM's 360 system strategy in the 1960's</td>
</tr>
<tr>
<td>Buyers are fragmented (many, different) - no buyer has any particular influence on product or price</td>
<td>Most consumer products</td>
</tr>
<tr>
<td>Producers supply critical portions of buyers' input - distribution of purchases</td>
<td>Intel's relationship with PC manufacturers</td>
</tr>
</tbody>
</table>

Buyer power with respect to public funding in the genome sequencing industry is fairly concentrated, with only three primary customers of large-scale sequencing data (NHGRI, DOE, and Wellcome Trust). Additionally, switching costs associated with using one sequencing center versus another are essentially non-existent. This would tend to promote intense competition for funds between the roughly 16 major sequencing centers around the world.

As described in the “Barriers to Entry” section above, the Wellcome Trust provides genome sequencing funds exclusively to the Sanger Institute. Additionally, each of the centers tends to possess its own set of core competencies that are advantageous for certain types of sequencing projects. This differentiation between centers probably influences the NHGRI and DOE to continue allocating limited funds to a number of centers in order to maintain a balanced portfolio.

of sequencing capabilities. To some degree, this differentiation may curb intense direct competition.

4.3 Supplier Power

Producers in a given industry require inputs – labor, equipment, components, and other supplies. Suppliers of these inputs, if powerful, can exert a significant influence on the producer, such as selling raw materials at a high price to capture some of the industry's profits. The following table outlines some factors that determine supplier power.  

<table>
<thead>
<tr>
<th>Suppliers are Powerful if:</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credible forward integration threat by suppliers</td>
<td>Baxter International, manufacturer of hospital supplies, acquired American Hospital Supply, a distributor</td>
</tr>
<tr>
<td>Suppliers concentrated</td>
<td>Drug industry's relationship to hospitals</td>
</tr>
<tr>
<td>Significant cost to switch suppliers</td>
<td>Microsoft's relationship with PC manufacturers</td>
</tr>
<tr>
<td>Customers Powerful</td>
<td>Boycott of grocery stores selling non-union picked grapes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suppliers are Weak if:</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many competitive suppliers - product is standardized</td>
<td>Tire industry relationship to automobile manufacturers</td>
</tr>
<tr>
<td>Purchase commodity products</td>
<td>Grocery store brand label products</td>
</tr>
<tr>
<td>Credible backward integration threat by purchasers</td>
<td>Garment industry relationship to major department stores</td>
</tr>
<tr>
<td>Customers Weak</td>
<td>Travel agents' relationship to airlines</td>
</tr>
</tbody>
</table>

Two of the suppliers to the genome sequencing industry exert significant power. Applied Biosystems (ABI) makes the DNA sequence detectors that account for the largest capital expenditure in all the publicly-funded genome sequencing centers. Additionally, ABI produces the proprietary biological reagent (Big Dye) that is used in conjunction with the detectors it sells. GE's Amersham Biosciences division makes another proprietary biological reagent (Templiphi) that is now used by a number of sequencing centers (some centers continue to use a SPRI-based PCR process that does not require the use of the Templiphi reagent). At the Broad Institute, these two biological reagents account for roughly 60 to 70% of the annual direct spend for materials (see Figure 5 below).

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Other major suppliers, such as Invitrogen, have achieved some power as a supplier to the sequencing centers. It is clear that powerful suppliers such as ABI, GE, and Invitrogen, are able to extract the greatest amount of value and have become the most successful businesses related to this industry. The Broad Institute has made attempts to backwards integrate or switch to other suppliers as a response to their powerful suppliers. However, these attempts have ultimately proved to be unsuccessful.

4.4 Threat of Substitutes

Substitute products refer to products in other industries. The price of aluminum beverage cans is constrained by the price of glass bottles, steel cans, and plastic containers. While these containers are substitutes, they do not directly compete with containers in the aluminum can industry. To a manufacturer of automobile tires, tire re-treads are a substitute. Today, new tires are so inexpensive that car owners typically do not give much consideration to re-treading old tires. In contrast, in the trucking industry new tires are expensive and re-treads remain a viable substitute. In general, a close substitute product constrains the ability of firms in an industry to raise prices.31

Genomic sequencing is one of several novel technologies that promise to address the widely publicized decline in drug development productivity. These novel technologies, including combinatorial chemistry, high-throughput screening, and systems biology, can be considered substitutes for one another in the sense that if the price associated with one of these technologies dropped, demand for the others would likely decrease. Thus, the existence of these other

technologies constrains the demand in the genome sequencing industry and limits the price that sequencing centers could attempt to charge their customers.

In addition to price playing a role in affecting demand for a given technology, certainly the perception of value derived from each technology plays a much larger role. If the perceived value of a given technology increases, the demand for that technology will likely increase, while the demand for the competing technologies will likely decrease. In a sense, all of the novel technologies aimed at addressing the drug development productivity decline are competing for limited resources.

4.5 Rivalry

In the traditional economic model, competition among rival firms drives economic profits to zero. But competition is never perfect and firms are not typically unsophisticated passive price takers. Rather, firms strive for a competitive advantage over their rivals and the intensity of these rivalries varies significantly across different industries. 32

An analysis of rivalry between publicly-funded genome sequencing centers is complicated because these centers do not operate in a purely capitalistic market and many of the major sequencing centers are part of not-for-profit organizations. Acknowledging these complications, a traditional rivalry analysis is still helpful to understanding the competitive environment.

The following characteristics of the genome sequencing industry promote intense rivalry within the industry:

- The large number of sequencing centers (16) increases rivalry because more firms must compete for the same customers and resources.
- The recent slow market growth causes the sequencing centers to fight for market share. In a growing market (which is not the case for genome sequencing), firms are able to improve revenues simply because of the expanding market.
- The low switching costs associated with using one sequencing center versus another increases rivalry. Because the customers of sequencing centers can freely switch from one center to another there is a greater struggle to capture customers.
- High exit barriers cause a firm to remain in an industry, even when the venture is not profitable. A significant exit barrier in the genome sequencing industry is the capital equipment – the DNA sequencing detectors used by all sequencing centers are very expensive and specialized for the industry. Because these detectors are highly specialized they cannot be sold to buyers in another industry (although perhaps they could be sold to other sequencing centers). Thus, even the underperforming sequencing centers may find it difficult to stop competing given the large fixed (sunk) costs they have already incurred.

Perhaps the most significant factor that may promote weak rivalry between sequencing centers is the differentiation in capabilities between each which would tend to result in less direct competition for projects. For example, many of the publicly-funded centers possess intellectual

32 Source: Porter, Michael E., “Competitive Strategy.”
property that provides an advantage over the competition with respect to certain types of projects. Additionally, some centers have focused their sequencing processes sequence specific types of organisms and may only compete for projects that fit their capabilities.

4.6 Choosing an Optimal Strategy

Even though an industry may have below-average profitability, a firm that is optimally positioned within that industry can generate superior returns. A firm should position itself by leveraging its strengths. Porter has argued that a firm’s strengths fall into one of two categories: cost advantage or differentiation. By applying these strengths in either a broad or narrow scope, three generic strategies result: cost leadership, differentiation, and focus. They are called generic strategies because they are not firm or industry dependent. The following table illustrates Porter’s generic strategies:

<table>
<thead>
<tr>
<th>Target Scope</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad (Industry Wide)</td>
<td>Cost Leadership</td>
</tr>
<tr>
<td>Narrow (Market Segment)</td>
<td>Focus Strategy (low cost)</td>
</tr>
</tbody>
</table>

In examining each of these generic strategies, it is clear that the chosen strategy for Broad’s Genome Sequencing Operations is the cost leadership strategy. This strategy calls for being the low cost producer in an industry for a given level of quality. A typical for-profit firm pursuing this strategy sells its products either at average industry prices to earn a profit higher than that of rivals, or below the average industry prices to gain market share. In the case of Broad’s not-for-profit Genome Sequencing Group, this strategy should allow this group to be successful competing for and securing grant money from the NHGRI and DOE through its low-cost capability.

A cost leadership strategy requires the relentless pursuit of cost reduction through means such as: building the operational capability of the organization; pursuing promising technological innovations; providing incentive mechanisms for employees based on meeting objective and quantifiable performance targets; and cost minimization in areas like R&D, organizational overhead, and so on. Historically, Broad’s Genome Sequencing Group has achieved and

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33 Source: Porter, Michael E., “Competitive Strategy.”
defended its cost leadership position through excelling in the area of technological innovation. However, this group has not demonstrated a significant competitive advantage in the other areas that enable cost reduction such as operational capability and incentive mechanisms. Broad’s Sequencing Group should attempt to prolong its cost leadership position in the genome sequencing industry by maintaining its excellence in the area of technological innovation while further developing its capabilities along the other important dimensions.

Additional ways that Broad’s Genome Sequencing Group can acquire cost advantages are by gaining unique access to a large source of lower cost materials, making optimal outsourcing and vertical integration decisions, or avoiding some costs altogether. If other sequencing centers are unable to lower their costs by a similar amount, then the Broad Sequencing Group may be able to sustain a competitive advantage based on cost leadership.

To sustain a cost leadership position requires continued reinvestment in organizational capability. While all competitive advantage is only temporary, firms can prolong their positions as cost leaders through reinvestments that ultimately lead to cost reductions. For a typical for-profit firm in a cost leadership position, a portion of its operating profits are reinvested in organizational capabilities such as state-of-the-art equipment and employee development—capabilities that enable the firm to make further cost reductions. In the not-for-profit world in which Broad’s Genome Sequencing Group operates and in lieu of the operating profits that would otherwise be achieved in the for-profit world, Broad’s managers must ensure that sufficient reinvestment is allowed to funnel back into the organization to enable continued cost leadership.

Although the low-cost strategy has proven to be effective in a variety of industries, as with any of the generic strategies it does have its share of risks. For example, firms may be able to lower their costs to level at or below those of the cost leader. Additionally, as technology improves or proprietary knowledge is gained, the competition may be able to leapfrog the low-cost firm in production capabilities, thus eliminating or obliterating the competitive advantage. Further, several firms following a focus strategy and targeting narrow markets may be able to achieve an even lower cost within their narrow segment and as a group gain significant market share. As an example, assume that the processes to sequence fungal DNA are very different from processes used to sequence mammalian DNA. Under this scenario, two focused firms each devoted to fungal and mammalian sequencing, respectively, may achieve lower costs than a single firm that chooses to sequence both. Nevertheless, the current optimal strategy for Broad’s Genome Sequencing Operations is the low-cost strategy, which is also known as the operational excellence strategy.
5 Choosing Performance Objectives

Now that a high-level strategy has been chosen, it is time to choose some explicit performance objectives as an important step towards translating strategy into measures for the scorecard (see Figure 6 below).

![Figure 6. Translating with the Balanced Scorecard.](image)

Performance objectives are frequently developed through the analysis of questions relating to each of the four perspectives:

- **Customer**: Who are our customers, and how do we add value for them?
- **Financial**: How do we maintain service levels while adhering to budgetary restraints?
- **Internal Processes**: Which processes must we excel at in order to continue adding value for customers?
- **Employee Learning and Growth**: Which organizational infrastructure elements are necessary if we hope to execute our strategy?

Note that as objectives are developed, and, later, measures, it will be critically important to continually evaluate them in light of changing circumstances or simply for the sake of continuous improvement. Based on the current strategy of operational excellence, the following performance objectives were developed for Broad’s Sequencing Operations:

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Customer

- Strengthen customer trust in our ability to provide high-quality sequencing data with no mix-ups.
- Increase our customer responsiveness by providing faster turn-around times.

Financial

- Increase employee productivity.
- Reduce our cost to sequence an entire mammalian genome.

Internal Processes

- Increase our flexibility to handle several projects in parallel.
- Be more efficient in developing and implementing next generation process technologies.
- Improve the capability of our supplier base to serve our needs.
- Reduce on-site materials inventory levels.

Employee Learning and Growth

- Increase employee satisfaction.
- Strengthen the capabilities of our employees to initiate and implement continuous improvement.

Included in the customer perspective is an objective that emphasizes the importance of strengthening Broad’s reputation for publishing high-quality genome sequence data. While few external quality problems have ever arisen in the Broad’s history, a few very notable incidents have happened, primarily due to mix-ups of DNA samples resulting in published sequence for one organism containing sequence from a DNA sample of another organism. Two such incidents are known to have occurred in the past, and both had resulted in notable scientists from other research organizations notifying the head of the Broad Institute of the quality issues, causing some reputation damage to the Broad.\textsuperscript{36} Therefore, as important as all the other objectives are, this one stands out as being absolutely crucial.

Another important objective which is included in the internal processes perspective is: “Increase our flexibility to handle several projects in parallel.” This particular objective reflects a relatively recent development in the genome sequencing industry where comparative genomics projects are garnering more and more attention from Broad’s primary customers, the NHGRI and DOE. Comparative genomics projects typically require genome sequence data from multiple organisms that all have nearly identical DNA codes. This requirement necessitates that Broad develops the appropriate systems and processes that allow for multiple, similar DNA samples to be run in parallel, and these systems and processes must also safeguard against potential mix-ups of DNA samples.

\textsuperscript{36} Source: Vokoun, Matthew, “Operations Capability Improvement of a Molecular Biology Laboratory in a High Throughput Genome Sequencing Center.”
The other performance objectives listed above are self-explanatory and mostly focus on decreasing sequencing production costs and reducing production flow time. One particular objective included in the employee learning and growth perspective, “Strengthen the capabilities of our employees to initiate and implement continuous improvement”, is derived from a recent change initiative to provide training and subsequently certify selected Broad employees in the techniques of Six Sigma process improvement. The intent of including this particular objective in the creation of Broad’s Balanced Scorecard is to help improve the chances of a successful adoption of Six Sigma practices within the organization.
6 Developing Measures, Targets, and Initiatives

6.1 Measures

The next step in the Balanced Scorecard journey is to choose appropriate performance measures for the performance objectives. Performance measures may be considered standards used to evaluate and communicate performance against expected results. A properly constructed scorecard should tell the story of an organization’s strategy through a sequence of cause-and-effect relationships. In fact, every measure selected for a Balanced Scorecard should be an element of a chain of cause-and-effect relationships that communicates the meaning of the organization’s strategy to its employees. Additionally, a well-designed scorecard should have a balance between measures of outcomes and performance drivers. Outcome measures tend to be lag indicators, such as profitability, market share, customer retention, and employee skills. Performance drivers, on the other hand, are lead indicators that reflect the current capabilities of an organization. 37

Additional characteristics of good performance measures are that they: are easy to understand; can be updated frequently; are accessible in that a large portion of data for the measures already exists; and are quantitative. 38 With these desirable characteristics in mind, the following performance measures were chosen for Broad’s Genome Sequencing Group:

Table 4. Performance Measures for Broad’s Genome Sequencing Group.

<table>
<thead>
<tr>
<th>Performance Objectives</th>
<th>Performance Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Customer</strong></td>
<td></td>
</tr>
<tr>
<td>C1  – Strengthen Trust in Quality Mix-ups</td>
<td></td>
</tr>
<tr>
<td>C2  – Faster Turn-around Times Project Completion Time</td>
<td></td>
</tr>
<tr>
<td><strong>Financial</strong></td>
<td></td>
</tr>
<tr>
<td>F1  – Increase Employee Productivity Cost Versus Competitors’, Direct Cost per Read</td>
<td></td>
</tr>
<tr>
<td>F2  – Reduce Sequencing Costs</td>
<td></td>
</tr>
<tr>
<td><strong>Internal Processes</strong></td>
<td></td>
</tr>
<tr>
<td>I1  – Increase Project Flexibility Projects Running in Parallel Process Development Cycle Time</td>
<td></td>
</tr>
<tr>
<td>I2  – Efficiently Implement New Process Technologies Number of Quality-Related Materials Issues Inventory Turnover</td>
<td></td>
</tr>
<tr>
<td>I3  – Improve Capability of Supplier Base Number of Suppliers, Lead Times</td>
<td></td>
</tr>
<tr>
<td>I4  – Reduce Materials Inventory Levels</td>
<td></td>
</tr>
<tr>
<td><strong>Employee Learning and Growth</strong></td>
<td></td>
</tr>
<tr>
<td>E1  – Increase Employee Satisfaction Satisfaction Survey</td>
<td></td>
</tr>
<tr>
<td>E2  – Strengthen Continuous Improvement Capabilities Rate of Improvement Projects Completed Six Sigma Certifications</td>
<td></td>
</tr>
</tbody>
</table>

There are a total of sixteen measures chosen, which is good according to one rule of thumb that there should be one and a half as many measures as objectives (and there are ten objectives). Of the sixteen measures chosen, seven are outcomes and nine are performance drivers, a fairly balanced mix. Additionally, most of the measures selected require data that is already tracked or is reasonably accessible.

A good practice after selecting performance measures is to define precisely what will be measured. This can be accomplished through a process of creating a performance measure data dictionary. Here is an example of a data dictionary for the “Inventory Turnover” performance measure:

<table>
<thead>
<tr>
<th>Table 5. Balanced Scorecard Data Dictionary for “Inventory Turnover” Measure.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Perspective:</strong> Customer</td>
</tr>
<tr>
<td><strong>Strategy:</strong> Operational Excellence</td>
</tr>
<tr>
<td><strong>Description:</strong> Inventory turnover measures how often during the course of a year Broad replaces its inventory of raw materials. An increase in Broad’s inventory turnover rate suggests that Broad is getting more out of the dollars it has tied up in inventory.</td>
</tr>
<tr>
<td><strong>Formula:</strong> Dollars spent on raw materials in the previous quarter multiplied by four and divided by the average amount of inventory, in dollars, held on-site during the previous quarter. The average amount of inventory held on-site during the previous quarter will be calculated by taking the average of two values: 1) the amount of inventory on-site at the beginning of the quarter, and 2) the amount of inventory on-site at the end of the quarter.</td>
</tr>
<tr>
<td><strong>Data Source:</strong> Broad’s MRP System</td>
</tr>
<tr>
<td><strong>Data Quality:</strong> Good</td>
</tr>
<tr>
<td><strong>Baseline:</strong> 5.4</td>
</tr>
<tr>
<td><strong>Target Rationale:</strong> tbd</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

6.2 Targets

Targets represent the desired results of performance measures. A comparison between actual performance results and predetermined targets adds value and meaning to the Balanced Scorecard. For example, assume that one particular city can fill a pothole within two days of notice, while neighboring cities can do it in just one. Further, the best cities can fill a pothole in three hours. Armed with this knowledge, perhaps a good initial target for this city is to fill potholes within twelve hours. With appropriate targets in place, organizations have a point of reference that helps to guide actions and decisions. The result is that improvement, not the status quo, is reinforced and communicated.39

Targets typically represent goals for some period in the future. They may be established by month, quarter, half-year, year, or multi-years. Most organizations develop annual performance

targets for their performance measures. Whenever possible, it is desirable to decompose annual
targets into increments that correspond to the chosen scorecard reporting frequency.\textsuperscript{40}

A recent survey of more than 500 studies indicates that performance increases by an average of
16 percent in companies that pre-establish targets.\textsuperscript{41} Experts reason that this improvement is
explained by the power of public commitment. When people make public commitments, such as
those in a written performance target, they tend to stick to them. The most common advice
associated with setting targets is to keep them realistic, yet challenging.\textsuperscript{40}

### 6.3 Initiatives

Initiatives are the specific programs, activities, projects, or actions that an organization will
engage in to help ensure it meets or exceeds performance improvement targets. An initiative
could be anything from implementing a Materials Resource Planning (MRP) system to
developing a next-generation genome sequencing process. While the nature of an organization’s
various initiatives will differ tremendously, one common thread that should run through all is a
clear linkage to strategic objectives, targets, and measures. Targets supply a star to shoot for, and
initiatives should be put in place to help achieve those targets.\textsuperscript{40}

A useful exercise to undertake upon completing a scorecard is to map current organizational
initiatives to the scorecard objectives. Any initiative that cannot demonstrate a clear linkage to an
objective should be a strong candidate for removal. Most organizations, and especially non-profit
organizations, do not suffer from a lack of initiatives. Using the scorecard to justify initiatives,
and, more importantly, eliminate initiatives that produce no value, is one sure way to provide a
quick economic payoff. Eliminating initiatives that don’t contribute to an organization’s strategy
frees up valuable resources that can be directed toward initiatives that will propel an organization
towards its goals.\textsuperscript{40}

\textsuperscript{40} Source: Niven, Paul R., “Balanced Scorecard: Step-by-step for Governmental and Nonprofit Agencies.”
\textsuperscript{41} Source: Locke, Edwin A., “Motivation by Goal Setting.”
7 Cascading the Balanced Scorecard

Cascading refers to the process of developing Balanced Scorecards at every level of the organization. The scorecards constructed at lower levels should align with the highest-level scorecard through the development of measures that lower-level groups will track in order to gauge their contribution to overall success. While some measures will be used throughout an organization on every scorecard, such as employee satisfaction, most measures will be unique to the lower-level groups. As scorecards are created at lower levels of an organization, employees from every function and level should be given the opportunity to comprehend how their actions can lead to improved results for everyone. The performance of an entire organization is no longer limited to a few high-level indicators that probably serve as an abstraction for most employees.\(^{42}\)

The success of cascaded scorecards is contingent upon many factors. Cascaded scorecards are most effective and should only be developed once the highest-level scorecard is thoroughly understood by the organization. Further, the terminology used in relation to the scorecards must be consistent throughout the organization (i.e. all scorecards should use the same perspectives – Customer, Financial, Internal Process, and Employee Learning and Growth – and the same terms objective, measure, target, and initiative). And it is not uncommon for lower-level organizations to have fewer measures than the high-level scorecard. Some groups simply do not have a measurable effect on certain high-level objectives. Additionally, first-level supervisors are critical to the acceptance of the scorecard system and their commitment and use of the Balanced Scorecard is a critical success factor. Finally, most of the steps associated with creating a high-level scorecard must be followed when creating low-level scorecards (i.e. measures selected, data dictionaries created, targets chosen, and initiatives to reach those targets identified).\(^{43}\)

The Broad’s Genome Sequencing Operations is comprised of five separate groups (see Figure 7 below) and unique Balanced Scorecards should be created for each. To demonstrate how this is accomplished the creation of performance measures for three of the groups is presented in this chapter (Molecular Biology Production, Supply and Quality Management, and Core Sequencing Production).

---


7.1 Molecular Biology Production Group

The Molecular Biology Production Group (MBPG) is the most upstream part of Broad’s genome sequencing operation. Essentially, the MBPG scales up raw DNA to a quality and quantity necessary for the subsequent high-volume, automated genome sequencing process.

Since the completion of the Human Genome Project, MBPG has been challenged to transition from a low-mix project environment (one long project with only human DNA) to a high-mix project environment (many short projects with DNA from many different organisms). Thus, improving its flexibility to deal with this high-mix environment is one critical performance driver for this group. Another critical performance driver that is even more critical than flexibility is quality. All quality problems that leave MBPG will drive costs up significantly and reduce the quantity of valuable output at the bottleneck process step. With these critical issues in mind, the following performance measures were chosen for Broad’s Molecular Biology Production Group.

<table>
<thead>
<tr>
<th>Performance Objectives</th>
<th>Performance Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td></td>
</tr>
<tr>
<td>C1 – Strengthen Trust in Quality</td>
<td>Number of Mix-ups</td>
</tr>
<tr>
<td>C2 – Faster Turn-around Times</td>
<td>Throughput Time</td>
</tr>
<tr>
<td>Financial</td>
<td></td>
</tr>
<tr>
<td>F1 – Increase Employee Productivity</td>
<td>Direct Materials Cost per Read</td>
</tr>
<tr>
<td>F2 – Reduce Sequencing Costs</td>
<td>Quality Reads per Employee</td>
</tr>
<tr>
<td>Internal Processes</td>
<td></td>
</tr>
<tr>
<td>I1 – Increase Project Flexibility</td>
<td>Number of Organisms (projects) per Employee</td>
</tr>
<tr>
<td>I2 – Efficiently Implement New Process Technologies</td>
<td>Number of Quality-Related Materials Issues</td>
</tr>
<tr>
<td>I3 – Improve Capability of Supplier Base</td>
<td></td>
</tr>
<tr>
<td>I4 – Reduce Materials Inventory Levels</td>
<td></td>
</tr>
<tr>
<td>Employee Learning and Growth</td>
<td></td>
</tr>
<tr>
<td>E1 – Increase Employee Satisfaction</td>
<td>Rate of Improvement Projects Completed</td>
</tr>
<tr>
<td>E2 – Strengthen Continuous Improvement Capabilities</td>
<td></td>
</tr>
</tbody>
</table>

7.2 Supply and Quality Management Group

The Supply and Quality Management Group is a support group responsible for managing the supply chain for materials used by all groups at Broad. However, the vast majority of its activities are to support genome sequencing operations and as a result the group is considered part of the Genome Sequencing Group.
Within most organizations, support groups are labeled as pure overhead, thereby diminishing their valuable role. Despite this tendency, support groups should have the same opportunity as any other department to demonstrate their contributions, and the Balanced Scorecard helps enable this. The quest for a support group is to understand how they play a role of higher-level scorecard success. With these issues accounted for, the following performance measures were chosen for Broad’s Supply and Quality Management Group:

<table>
<thead>
<tr>
<th>Performance Objectives</th>
<th>Performance Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Customer</strong></td>
<td></td>
</tr>
<tr>
<td>C1 – Strengthen Trust in Quality</td>
<td></td>
</tr>
<tr>
<td>C2 – Faster Turn-around Times</td>
<td>Stockout Occurrences</td>
</tr>
<tr>
<td><strong>Financial</strong></td>
<td></td>
</tr>
<tr>
<td>F1 – Increase Employee Productivity</td>
<td></td>
</tr>
<tr>
<td>F2 – Reduce Sequencing Costs</td>
<td>Cost of Expired Materials</td>
</tr>
<tr>
<td><strong>Internal Processes</strong></td>
<td></td>
</tr>
<tr>
<td>I1 – Increase Project Flexibility</td>
<td></td>
</tr>
<tr>
<td>I2 – Efficiently Implement New Processes</td>
<td></td>
</tr>
<tr>
<td>I3 – Improve Capability of Supplier Base</td>
<td>Number of Quality-Related Materials Issues</td>
</tr>
<tr>
<td>I4 – Reduce Materials Inventory Levels</td>
<td>Inventory Turnover</td>
</tr>
<tr>
<td><strong>Employee Learning and Growth</strong></td>
<td></td>
</tr>
<tr>
<td>E1 – Increase Employee Satisfaction</td>
<td></td>
</tr>
<tr>
<td>E2 – Strengthen Continuous Improvement Capabilities</td>
<td>Rate of Improvement Projects Completed</td>
</tr>
</tbody>
</table>

7.3 **Core Sequencing Production Group**

The Core Sequencing Production Group runs the most costly and automated portion of the entire genome sequencing operation. This group is responsible for producing dye-terminated segments of sample DNA and analyzing these DNA segments using its sophisticated detection equipment.

The majority of Broad’s direct materials spend and capital expenditures is driven by the processing requirements of this group as Core Sequencing consumes relatively large amounts of high-priced proprietary biological reagents (Templiphi and Big Dye, see Figure 5) and utilizes the expensive DNA sequence detectors. This group has a very significant influence on the performance of Broad’s Genome Sequencing Group as a whole, especially along the measures of cost and throughput time.

---

Table 8. Performance Measures for Broad’s Core Sequencing Production Group.

<table>
<thead>
<tr>
<th>Performance Objectives</th>
<th>Performance Measures</th>
<th>Outcomes</th>
<th>Performance Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1 – Strengthen Trust in Quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2 – Faster Turn-around Times</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td></td>
<td>Throughput Time</td>
<td>Pass Rates, Q20s per Read, Detector Availability</td>
</tr>
<tr>
<td>Financial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1 – Increase Employee Productivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2 – Reduce Sequencing Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial</td>
<td></td>
<td>Direct Materials Cost per Read</td>
<td>Quality Reads per Employee, Big Dye and Templiphi Yields</td>
</tr>
<tr>
<td>Internal Processes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1 – Increase Project Flexibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I2 – Efficiently Implement New Process Technologies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I3 – Improve Capability of Supplier Base</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I4 – Reduce Materials Inventory Levels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Processes</td>
<td></td>
<td>Number of Quality-Related Materials Issues</td>
<td></td>
</tr>
<tr>
<td>Employee Learning and Growth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1 – Increase Employee Satisfaction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2 – Strengthen Continuous Improvement Capabilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employee Learning and Growth</td>
<td></td>
<td>Rate of Process Improvement, Projects Completed</td>
<td>Satisfaction Survey, Six Sigma Certifications</td>
</tr>
</tbody>
</table>

Just as cascaded scorecards have been developed for three of the five sub-groups within Broad’s Genome Sequencing Group, scorecards should also be developed for the other two (Special Projects and Technology Development). Yet, the process of cascading is not necessarily finished once this step is complete. The most effective Balanced Scorecard implementations use cascaded scorecards all the way down to the individual employee level such that significant portions of each employee’s performance review is based on his or her contributions to overall organization success and performance improvement. This detailed level of cascading creates extrinsic motivation for employees and can guide them to make contributions in areas that their managers’ explicitly value the most.
8 Implementing a Balanced Scorecard at Broad

Getting to the point where an organization can actually begin to use a Balanced Scorecard system goes far beyond merely designing the scorecard and choosing appropriate measures and targets. Successfully implementing a scorecard is perhaps the most complicated and challenging part the process. The success of any scorecard implementation is based on several complicated factors. Luckily, hundreds and even thousands of firms have provided us with examples of successful and unsuccessful scorecard implementations from which we can learn.

This chapter provides two functions. The first is to share some of the best-practices of scorecard implementations as gleaned from hundreds of organizations who have implemented scorecarding systems (section 8.1). In light of these best-practices, various aspects of the scorecard implementation at Broad are discussed. The second function of this chapter is to provide Broad with some tactical recommendations for implementing its very own Balanced Scorecard performance measurement system (sections 8.2 through 8.4).

8.1 Best-Practices of Scorecard Implementations

While the implementation of Balanced Scorecards can benefit organizations in numerous ways, organizations can fail to achieve these benefits if they do not consider some important issues relating to the implementation of such systems. Results from previous scorecard implementations suggest that there are two key issues that must be addressed in any successful scorecarding system implementation. First, an organization needs to establish the motivation for implementing the scorecarding system. Second, there needs to be the presence of a supportive organizational environment, without which a performance management system will ultimately fail. Careful design and implementation of the Balanced Scorecard will help ensure the success of the system.45

8.1.1 Establishing Motivation

As presented in section 2.3.1 of this thesis, the primary objectives for implementing a Balanced Scorecard for Broad’s Genome Sequencing Group are the following:

- Provide a catalyst for the further development of operations capability.
- Align employee efforts to strategic goals.
- Fully engage all employees and motivate them to achieve performance improvements.

The reasons for implementing scorecarding systems can typically be grouped into two general categories: tactical and strategic. In most successful Balanced Scorecard implementations the primary reasons for implementing the system is strategic. While there are certainly some tactical reasons to implement a Balanced Scorecard at Broad – like satisfying the need to track progress toward organizational targets; the need to communicate strategy to everyone; the need to align employee behavior with strategic objectives; being able to measure people and projects – the primary motivation for implementing a scorecard is to make a long-term strategic investment in further developing Broad’s operations capability.

45 Source: Lawson, Raef, et. al., “Scorecarding in North America.”
8.1.2 Ensuring a Supportive Organizational Environment

No Balanced Scorecard implementation can be successful without the presence of a supportive organizational environment. Most critical in this respect is the need for buy-in from top-level management within the organization. As in most organizations, the senior managers within Broad’s Genome Sequencing Group set the tone for all employees. Without the senior managers’ demonstration of total commitment and support, the Balanced Scorecard Change initiative will be doomed to failure. If Broad’s leaders demonstrate only lukewarm support for the project, then employees that report to them will translate this as a sign that the project isn’t worth their time and effort.

Yet getting the support of top-level management is only necessary but not sufficient for a successful scorecard implementation. Another aspect that is nearly as critical is getting employees, especially front-line supervisors and managers, to accept and use the Balanced Scorecard system. An important step in obtaining this employee acceptance is to extensively communicate the reasons for the scorecard and the benefits to both the employees and the organization from having it in place.

Beyond gaining widespread acceptance of the Balanced Scorecard system, another key to success is making the system pervasive within the organization. Ultimately, employees’ performance evaluations, compensation, and rewards should be linked to an organization’s Balanced Scorecard measures. This linkage often results in increased employee motivation to achieve the strategic performance objectives included in the Balanced Scorecard. However, before taking this step of linking measures to employee reviews and compensation, Broad’s managers should be sure that their scorecard measures are valid and reliable, which often takes time. The process of cascading scorecards should occur in phases as confidence in each higher-level scorecard is achieved.

8.2 Forming a Balanced Scorecard Team

While much of the previous chapters were devoted to designing a Balanced Scorecard performance measurement system for Broad’s Genome Sequencing Group, the actual process of developing a final scorecard should be accomplished through a team approach that builds consensus and clarity throughout the organization. The final product of this development process should be a scorecard that represents the collective wisdom of the Broad’s senior managers and employees.

For an organization the size of Broad’s Genome Sequencing Group, an optimal team size is probably five or six. In order to get appropriate representation from across the organization, an effort should be made to involve employees from all the smaller groups that constitute the larger Genome Sequencing Group (Molecular Biology Production, Supply and Quality Management, Core Sequencing Production, Special Projects, and Technology Development). The representatives that serve as team members on the Balanced Scorecard initiative should be capable and well-respected members of their respective groups such that they will become effective ambassadors of the scorecard within their groups.
Ideally, the roles and responsibilities for individuals on the team should be as follows:\footnote{46 Source: Niven, Paul R., “Balanced Scorecard: Step-by-step for Governmental and Nonprofit Agencies.”}

- **Executive Sponsor.** As the senior member of the team, the sponsor should ensure the team receives the resources necessary for a successful implementation. The sponsor should also be an active advocate and ambassador of the Balanced Scorecard.

- **Team Leader.** The team leader should be a change agent who provides leadership and ensures a successful implementation. This role is very challenging and requires someone who has credibility and is a skilled communicator and facilitator. The team leader should provide full-time support to the project.

- **Team Members.** Team members should be engaged in all aspects of the Balanced Scorecard creation and implementation. They are also relied upon to bring specialized knowledge of their own functional areas and to be ambassadors of the scorecard within their respective groups.

### 8.3 Designing a Balanced Scorecard: The Process

Once high-level support has been secured and the Balanced Scorecard team has been formed, the next step is to develop the scorecard that will be used for Broad’s Genome Sequencing Operations. The work documented in the previous chapter should be useful to the team leader as a guide and reference for the creation of the final scorecard. Yet, the team leader should not simply present this scorecard to the Balanced Scorecard team for ratification. This action would likely be counterproductive, as the purpose for forming a team is to create a scorecard that represents the collective wisdom of its creators and to gain commitment for the implementation phase of the project. Certainly, a shared commitment to implement the scorecard is not likely if the team is not fully involved in the development process.

As described in the previous chapters, there are five core steps involved in the actual design of a Balanced Scorecard:

1. Creating mission, value, and vision statements.
2. Formulating a strategy.
3. Choosing performance objectives for the scorecard.
4. Developing measures, targets, and initiatives for the scorecard.
5. Cascading the Balanced Scorecard to every level of the organization.

Prior to starting the design work, however, the team leader should devote one or two meetings to training the Balanced Scorecard team on the important features of the scorecard. Despite its apparent simplicity, the Balanced Scorecard is not as simple a tool to design as one might suspect. Thus, up-front training in addition to ongoing training will be necessary for a successful scorecard implementation.

A sample Balanced Scorecard training agenda for one of the up-front sessions is as follows:\footnote{46 Source: Niven, Paul R., “Balanced Scorecard: Step-by-step for Governmental and Nonprofit Agencies.”}

- **Describe the Broad’s “burning platform” –** the specific issues that the organization faces that require the organization to change. This discussion should include challenges
inherent in the genome sequencing industry and the heated competition between sequencing centers for grant money.

- Give background on the Balanced Scorecard and explain how it has become a state-of-the-art performance measurement and management tool.
- Describe the important features of the scorecard such as the four perspectives (customer, financial, internal processes, employee learning and growth) and the process of cascading the high-level scorecard down to the lower levels of the organization.
- Facilitate a discussion on how a Balanced Scorecard could benefit the organization and address some of the issues that are impacting it.
- Provide examples of success stories of other nonprofit (and possibly for-profit) organizations that have used the scorecard.

Upon completing one or two up-front training sessions, the work of actually designing the scorecard can begin. The timeframe for designing the high-level scorecard may take two to three months, with the team leader driving this schedule and facilitating weekly meetings with the Balanced Scorecard team. The team should work on the first four (out of five) core steps in order. The fifth step, cascading the scorecard, can be considered a separate activity that takes place after the initial high-level Balanced Scorecard has been fully implemented.

In order to make satisfactory progress towards the design of the high-level scorecard, the team leader should create a timeline for each of the major activities that will be part of the design process. An example of a timeline is presented below in Figure 8. More than just creating a timeline, the team leader needs to gain the commitment of the team to meet the deadlines of the timeline. Additionally, the team leader must monitor progress on an ongoing basis to ensure the project is on track. It may be the tendency of employees at Broad to de-prioritize the scorecard project in favor of “firefighting” activities related to production issues.

![Figure 8. Timeline for Designing a Balanced Scorecard at Broad.](image-url)

#### 8.4 Implementing the Balanced Scorecard

In order for the implementation of the scorecard to be successful, the Balanced Scorecard team should develop a reasonably detailed implementation plan. This plan should include:
• Communicating the Balanced Scorecard throughout Broad’s Genome Sequencing Group.
• Assigning responsibilities for capturing and reporting scorecard data.
• Training the appropriate employees how to collect the data necessary to populate the scorecard.
• Determining which management processes will be changed as a result of implementing the Balanced Scorecard.
• Deciding when and how often the results of the Balanced Scorecard will be reported (typical frequencies are monthly or quarterly and sometimes even annually).
• Facilitating the fifth core step of designing a Balanced Scorecard – cascading the scorecard to the smaller groups within Broad’s Genome Sequencing Group.

The focused implementation work should take up to a month, but even after this focused work is complete the Balanced Scorecard should continue to evolve and efforts should be undertaken to make it more fully integrated into Broad’s management systems. For example, as each of the groups begins using their second-level scorecards and metrics, the performance reviews of employees within these groups should be tailored to align to the scorecard system. Broad’s performance will assuredly improve when its employees can see a strong connection between their jobs and Broad’s most important goals.

At this point, with a Balanced Scorecard created and implemented, there will always be room to improve on the scorecard design itself. The scorecard should be viewed as a living document, one that should be modified as Broad’s strategy or vision changes, or, simply, as new or better metrics are identified. To ensure this continuous improvement aspect is built into the scorecard process, an annual or biannual review cycle is recommended.
9 Materials Change Management System

An additional opportunity for Broad to improve its operational performance is through the adoption of a process approach to its common operations activities. The driving principle behind a process approach is that desired results are achieved more efficiently when activities and related resources are managed as a process. Further, defining activities as a process allows for an objective analysis of which activities are absolutely necessary and which are simply waste, allowing for systematic improvement of these processes which leads to improved efficiencies and results. Examples of activities that are typically managed as processes within high-performing manufacturing environments include: supplier performance reviews, engineering changes, operator training, employee performance reviews, etc. This chapter focuses specifically on the design of an effective materials change management process (system) that was developed and implemented at Broad during the course of the internship.

9.1 Rationale for Implementing a Materials Change Management System

Broad’s Supply and Quality Management Group (SQMG) is responsible for managing the supply chain for materials used in Broad’s DNA sequencing process. With a supply chain that entails a $15 million annual direct material spend, 52 routine suppliers, and up to 832 types of materials purchased, the SQMG is frequently presented with opportunities to use better or cheaper materials from its current suppliers as well as alternate suppliers.

Historically, the SQMG has lacked the ability to effectively evaluate and implement materials changes due to an undisciplined and informal process that would sometimes require heroic efforts to overcome. Further, a number of previous materials changes had been made in the past without agreement from the appropriate stakeholders within the organization. A more streamlined process for evaluating and implementing materials changes was identified as a critical need for Broad in its ongoing efforts to continuously improve its performance. To address the need for a standardized materials change process the author set to design and implement a materials change management system according to the timeline in Figure 9.

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<tr>
<th>June</th>
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<td><strong>Benchmarking Activities</strong></td>
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<td><strong>Method to Quantify Risk</strong></td>
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<td><strong>Design a Materials Change System</strong></td>
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<td><strong>Oversee Materials Changes, Continuous Improvement</strong></td>
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Figure 9. Timeline for Designing and Implementing a Change Management System at Broad.
9.2 Benchmarking Results: Inter-Industry Change Management Methodologies

A majority of high-performing manufacturing organizations have some sort of change management system in place to manage engineering changes within the context of an established manufacturing process. Despite this fact, very little published literature is actually devoted to this area of change management. Through conversations with LFM classmates, an attempt was made by the author to understand the various inter-industry change management practices with the ultimate goal of designing a materials change management system for Broad’s Genome Sequencing Operations Group.

Employees, or former employees, from the auto, personal computer, aerospace, pharmaceutical, and semiconductor industries were asked questions about engineering change management systems in place within their respective organizations. While several differences did exist between the change processes of different companies and industries, there were some common and important themes to all these organizations’ change management methodologies:

- Potential changes are considered along the dimensions of cost, benefit, and risk.
- The process that is followed for a given engineering change is based on an initial risk assessment – lower risk changes tend to require less effort than higher risk changes.
- There are typically two review cycles: an initial review to determine the appropriate tests and corresponding success criteria associated with the change and a final review prior to full implementation of the change.

Some key differences between the companies’ change practices included: how the risk of a change is determined; whether the documentation of the change is done on paper or electronically; which people within the organization review the change; the level of scrutiny each change proposal is subjected to; how each change is classified; and whether the procedures for making a change are based on regulatory guidelines. With an understanding of the commonalities and differences that exist in change management practices across organizations and industries, the author sought to design and implement a practical materials change management system for Broad’s Genome Sequencing Group.

9.3 Cost-Benefit Framework

Proposed materials changes should be considered along the dimensions of benefits, costs, and risk. Benefits improve the performance of the Broad’s genome sequencing operations by positively impacting one or more key performance measures. Ultimately, while not necessarily a trivial exercise, these performance improvements should translate into dollars. Correspondingly, costs weaken any of Broad’s performance measures and this weakening should also translate into dollars. Clearly, only those change proposals that entail greater benefits than costs (in terms of dollars) should be considered. However, there is one other important factor to consider, risk. Risk is more abstract than both benefits and costs and, hence, is more difficult to deal with.

For change proposals to the materials Broad uses in its genome sequencing operations, a well-designed qualification plan can mitigate risk such that risk is translated into a cost by considering the effort associated with the qualification activities as an added cost (see Figure 10 below). This
methodology allows for a simpler cost-benefit analysis that essentially treats risk as a cost. Ultimately, any proposed materials change that does not withstand the scrutiny of a cost-benefit analysis should not be pursued.

![Figure 10. Basic Framework for Evaluating a Materials Change.]

9.4 Design of a Materials Change Management System for Broad

Genome sequencing involves biological processes that are highly complex and may exhibit sensitivity even to seemingly insignificant changes in raw materials inputs. Therefore, Broad’s Genome Sequencing Operations Group must maintain a high degree of control over the inputs it uses in its processes. One important aspect of controlling these inputs is the necessity of a system for managing any changes to the raw materials it uses.

Each material used in the various genome sequencing sub-processes has unique functionalities and corresponding risk attributes, so there can be no single, standard procedure for introducing all materials changes. The procedure defined for a materials change must therefore be custom-made for the change that is proposed. It is within this context that a practical materials change management system was designed which allows for flexibility and customization for each new change proposal.

The materials change management system designed for Broad’s Genome Sequencing Group focuses on five key areas, which are described in more detail below:

- Documentation
- Classification
- Qualification
- Approval
- Implementation
9.4.1 Documentation

In order to facilitate the proper communication of each materials change proposal and to capture
the relevant details associated with each proposed change, a “generic” change form was created
in Microsoft Word (see the Appendix). The form was designed in Word to allow for the
documentation of simple and straight-forward changes as well as complex changes by providing
the originator of the change form with an ability to leave some sections of the form blank or to
add additional sections as needed.

For each new change proposal, the originator of the change is responsible for providing all the
documentation. Typically, for the majority of change proposals, two forms are required: the first,
a “Preliminary” form, is used to get stakeholder agreement for which qualification activities and
success criteria will be necessary prior to implementing the change; the second, a “Final” form,
is used to get approval to fully implement the materials change. If the “Preliminary” form has
been approved and the subsequent tests meet the success criteria outlined in the “Preliminary”
form, then the expectation is that the stakeholders will approve the “Final” form without
resistance or additional scrutiny. Approved documents are sent to a specified person within the
Supply and Quality Management Group who uploads the documents into a file management
software application called eNovator where these documents are stored for historical reference.

9.4.2 Classification

The method by which changes are classified is one key difference between the change
management practices of the different organizations benchmarked. A proposed change can be
classified according to factors such as the magnitude or complexity of the change, strict
definitions based on the specific materials or processes being impacted, or risk considerations.
For Broad’s Genome Sequencing Operations Group, generic risk considerations are used to
classify changes as low (Level I), medium (Level II), or high risk (Level III) according to the
following guidelines:

Level I: A change that does not represent a fundamental change to the process technique
or material components and does not have any significant potential failure modes
associated with it. These changes typically require no formal qualification.

Level II: A change that does not represent a fundamental change to the process technique
or material components but does have one or more significant potential failure modes
associated with it. These changes will typically require a formal qualification plan to
prove equivalent or improved performance as well as to mitigate risk.

Level III: A change that does represent a fundamental change to the process technique or
material components. These changes require a formal qualification plan to prove
equivalent or improved performance as well as to mitigate risk.

The classification level establishes the appropriate reviewers of the change proposal and
indicates whether or not the change will require formal qualification activities. Because these
risk classification guidelines can be somewhat subjective, if there is any disagreement about the
correct classification level for a given change, the rule of thumb is to assign the higher level of risk to the change.

9.4.3 Qualification

All proposed materials changes with a potential to impact Broad’s genome sequencing process require a qualification plan that, when completed, will help ensure that there are no unintended negative consequences related to the change. Because each material used in the various genome sequencing sub-processes has unique functionalities and corresponding risk attributes, each qualification plan should be custom-made for the change that is proposed. There is typically an inverse relationship between process understanding and the number of qualification activities required. Thus, the content of the qualification plan should be determined by “process experts” within Broad’s Genome Sequencing Group to make sure the appropriate tests are performed, while unnecessary tests are avoided.

One tool that is useful in uncovering the risk factors associated with a change is a Failure Modes and Effects Analysis (FMEA). An FMEA is an advanced quality planning tool that is part of the suite of Six Sigma tools and is used for evaluating potential failure modes and their causes. An FMEA approach provides a method for considering the risks associated with a given material, and the analysis is conducted according to the following steps:

1. Determine the process functionality of the material.
2. Brainstorm potential failure modes.
3. Identify potential causes of each failure mode.
4. Determine the potential effects of the failures.
5. List the current process controls and procedures.
6. Assign Severity, Occurrence, and Detection ratings based on pre-determined scales.
7. Calculate the Risk Priority Number (RPN) (= Severity*Occurrence*Detection).

The Risk Priority Number provides a relative risk “score”, with a higher RPN indicating a higher relative risk. If Severity, Occurrence, and Detection ratings are based on 1 to 10 point scales then the minimum RPN is 1 while the maximum RPN is 1000. Table 9 below provides an example of how to conduct an FMEA analysis for a chosen material. The material in this example, Templiph, is used in the Core Sequencing sub-process to amplify plasmid DNA. One potential failure mode for this material is when the Templiph reagent is contaminated due to self-amplification. The potential effect of this failure is an inability to amplify the plasmid DNA, and hence no sequence data is produced when the DNA sample is eventually analyzed in the detectors. The potential cause of contamination is exposure to high temperatures during manufacturing, shipping, or storage. Severity, Occurrence, and Detection ratings of 6, 6, and 2 are assigned to this failure mode, respectively, based on pre-determined ratings scales. While a more rigorous numerical analysis would take into account any uncertainty in these assigned ratings, practitioners of failure mode analyses seem to prefer a single, discrete rating along each dimension.
The FMEA methodology described above is one good way to identify appropriate qualification tests that will address and monitor all potential material failure modes through process screening techniques, two sample t-tests, and other statistical methods. A well-designed qualification plan will mitigate the risk associated with the change as much as possible through creative means such as non-production testing or phased pilot tests. In documenting the qualification activities, specific success criteria should be established and agreed upon, and the corresponding qualification activities should be carried out according to the plan.

9.4.4 Approval

Proposed materials changes should be reviewed by the appropriate individuals within Broad’s Genome Sequencing Group based on the classification level of the change as described in section 9.4.2. Specific approval flows were established based on the classification level of the change and include individuals such as supervisors, managers, “process experts”, and even the director of the Genome Sequencing Group (see the Appendix).

The purpose of the approval step is to ensure that changes are scrutinized at the appropriate levels within the organization and to make sure that all aspects of the change are addressed including: the classification level; the potential benefits of the change relative to the costs; the appropriateness of the qualification plan; the details of the implementation plan; and the reviewers of the change. A formal approval is required for both “Preliminary” and “Final” proposed changes. As mentioned previously, reviewers are expected to approve a “Final” proposed change if all the success criteria outlined in the approved “Preliminary” form have been met.

9.4.5 Implementation

The implementation of the proposed materials change should occur upon receiving approval of the “Final” change form. To ensure (to the extent it is possible) a successful implementation of the materials change, the plan for all the implementation activities should be explicitly stated in the change form, with a timeline and owners assigned to each task. Lots of empirical data suggests that successful implementations are the result of good communication and planning. Two rules of thumb for every implementation are to: 1) over-communicate; and 2) over-plan. Ultimately, it is the originator of the change form who has the responsibility to ensure the implementation plan is followed to completion.
9.5 Case Study: Evaluating a Templiphi Formulation Improvement

9.5.1 Background of the Change

For nearly two years Broad's Genome Sequencing Group has been using a reagent supplied from GE's Amersham Biosciences division called Templiphi that rapidly and efficiently produces many copies of circular DNA within Broad's Core Sequencing process. The use of this Templiphi reagent represents a significant technological improvement over the previous version of Broad's Core Sequencing process, which employed a SPRI-based polymerase chain reaction. However, GE Amersham's current formulation of the Templiphi reagent has caused some significant problems at Broad over the last two years due to the reagent's susceptibility to self-amplification at sufficiently high temperatures. Templiphi is shipped to Broad on dry ice where it is stored at -80°C to keep the Templiphi inactive until it is allowed to liquefy on ice at 0°C for immediate use in Broad's amplification process. Despite these stringent precautions, on more than one occasion the Templiphi reagent has been activated prior to arriving at Broad. Recently, this self-activation was determined to be occurring within GE's manufacturing process, which has occasionally led to useless sequencing data at Broad.

To mitigate this contamination risk, Broad has inserted the following three quality control measures to ensure that each bottle of Templiphi it uses is contamination free:

1. **Pre-amplification lot acceptance test:** 100 “randomly selected” bottles (out of a total of 1200) are sampled from each new lot received. If the DNA level in any of the 100 bottles sampled exceeds Broad's specification limit then the entire Templiphi lot is rejected and GE Amersham is required to send a replacement lot at their own expense.
2. **Pre-amplification test on every bottle:** Each bottle of Templiphi that is scheduled for use in production is tested prior to being used. If the DNA level in a bottle exceeds the specification limit then that bottle is rejected and discarded at Broad's expense.
3. **Application of temperature tags:** Temperature tags were added to each kit of Templiphi (a kit consists of five bottles) by GE Amersham to aide in the diagnosis of the contamination problem. These tags indicate whether the Templiphi bottles are subjected to high temperatures for prolonged periods of time during transportation or storage.

Post the insertion of these risk mitigation measures, Broad has effectively avoided using contaminated Templiphi in its production process. Yet, bottles and lots that fail as well as the use of materials and labor for pre-amplification testing add up to significant costs for both GE Amersham and Broad. Thus, these two organizations have initiated a joint project to develop and use an improved formulation of the Templiphi reagent that remains inactive until the time of use (and thus this new formulation is not susceptible to self-amplification and contamination issues). An evaluation of this Templiphi formulation improvement project is presented here focusing on the areas of cost-benefit analysis, classification, and qualification.

9.5.2 Cost-Benefit Analysis of the Project

All proposed materials changes at Broad should be able to withstand the scrutiny of a cost-benefit analysis. While precise estimates along these two dimensions are not necessarily warranted in all cases, some care should be taken to ensure that each proposed change is
worthwhile based on an objective cost-benefit analysis. Table 10 summarizes the expected benefits associated with using a new Templiphi formulation that is inactive until use as compared to the current formulation which is prone to contamination issues. The total expected benefits to Broad by using the new formulation is estimated at $209K per year due to materials and labor savings that would result from the elimination of pre-amplification tests, no occurrences of rejected Templiphi bottles and lots, as well as savings from a reduction in inventory safety stock levels.

Table 10. The Expected Benefits from Using an Improved Templiphi Formulation.

<table>
<thead>
<tr>
<th>Item</th>
<th>Materials and Labor Savings</th>
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| Pre-amp QC lot acceptance test | Materials: $1490/lot = $8 K/yr  
                                 Labor: 8 hrs/lot = $1 K/yr |
| Pre-amp QC on every bottle  | Materials: $446/day = $89 K/yr  
                                 Labor: 2 hrs/day = $10 K/yr |
| Rejected Bottles            | Failed Bottles: 1 %  
                                 T-phi Losses: $51 K/yr |
| Rejected Lots               | Failed Lots: 2/yr  
                                 Redo Lot Acceptance Test: $1690/lot = $3 K/yr  
                                 Coordination: $2000/lot = $4 K/yr |
| Inventory Holding          | Old Inventory Holding Costs (ROP = 180, Order Quantity = 240): $138 K/yr  
                                 New Inventory Holding Costs (ROP = 90, Order Quantity = 240): $95 K/yr  
                                 Inventory Holding Savings: $43 K/yr |

The calculations in Table 10 are based on several key assumptions, including: every Templiphi lot consists of 240 kits (1200 bottles); Broad’s labor rate is $25 per hour; and the current Templiphi formulation results in two failed lots per year.

Relative to other routine materials changes, this Templiphi materials change entails a high level of risk that must be mitigated through carefully planned qualification tests. These qualification tests represent the only significant cost to Broad associated with implementing the new Templiphi reagent in its Core Sequencing process. The main source of these qualification costs is labor, which is required to coordinate and carry out the appropriate testing activities. Because the benefits of this change (a cost savings of ~$209K per year) will clearly outweigh any labor costs associated with the qualification of the change, a precise estimate of these qualification costs is unnecessary. The change to the new Templiphi formulation is indeed worthwhile based on a cost-benefit analysis.

9.5.3 Classification of the Change Proposal

GE Amersham has modified the Templiphi reagent to be inactive with increased shelf stability. GE has achieved this result through moving critical activation components to the denature buffer while taking other various steps to improve its own manufacturing process. This Templiphi formulation change is classified as a Level III change because it represents a fundamental change
to the material composition of the reagent. This classification level entails a formal qualification plan to prove equivalent or improved performance as well as to mitigate risk.

9.5.4 Qualification Activities

Prior to full implementation of the formulation change, qualification tests must be designed to demonstrate the expected benefits of the new reagent while showing that there are no unintended negative consequences related to the change. This will entail performing tests to show that the new Templiphi is inactive until use, has an improved shelf life compared to the current version, and demonstrates equivalent or better performance when used in Broad’s Core Sequencing process. Important performance measures of the Templiphi reagent are DNA product yield, amplification time, and typical sequencing quality measures such as pass rates and read lengths.

Although the specific details of the qualification tests are still under development, the high-level strategy for the qualification is to perform three phases of testing. The first phase is to perform a series of small-scale experiments to demonstrate that the reagent is inactive until use and exhibits increased shelf stability. The second phase is to carry out a series of tests between the new and current Templiphi formulations using DNA samples from several different project types currently running in production at Broad. Performance measures between the two formulations will be statistically analyzed to determine whether the new formulation exhibits equivalent or improved performance compared to the current formulation. Finally, the third phase of the qualification is to run a larger-scale pilot in production. During this pilot run the performance of the new Templiphi formulation should be closely monitored and batch to batch variation should be measured and compared to the baseline performance of the current formulation. Assuming the results of these tests are favorable, a full-scale implementation should ensue.
10 Materials Delivery, Quality Management, and Inventory Policies

This chapter provides a critical analysis of some of the important processes and policies employed by the Supply and Quality Management Group (SQMG). Included are brief overviews of selected lean manufacturing and business process reengineering concepts followed by a description of actual initiatives undertaken to improve SQMG’s processes and policies during the course of the six and a half month internship.

10.1 Lean Manufacturing and Kanban Overview

Lean Manufacturing is a business initiative focused on reducing waste in manufactured products and their related processes. The central belief in Lean is that the cause of poor performance in any organization is wasteful activity. Taichi Ohno, the main architect of the Toyota Production System and the pioneer of Lean, classified seven types of waste in manufacturing: 1) producing defective products; 2) producing too much product; 3) carrying inventory; 4) waiting due to unbalanced workloads; 5) unnecessary processing; 6) unnecessary worker movement; and 7) transporting materials. The sources of all this waste can ultimately be traced to underlying process imperfections, environmental variables, or management practices. Increased competitive advantage comes from eliminating waste and assuring every task is focused on rapid transformation of raw materials into finished product.47

Lean Manufacturing typically results in reduced overhead operating costs, shortened lead times, reduced inventory levels, increased sales and profits, and lower on-the-job employee frustration. This operations management concept provides a strategic approach to integrated improvements through value stream mapping and the focus on maximizing the value-adding-to-waste ratio. It directly promotes and advocates radical breakthrough innovation, while also emphasizing fast response to obvious improvement opportunities. Finally and most importantly, Lean addresses workplace culture and resistance to change through direct team involvement at all levels of the organization.48

Lean Manufacturing has developed many standard tools and principles. One such tool, termed kanban, was found especially useful for improving selected processes at Broad during the course of the internship. Kanban is a Japanese noun, meaning “visible record”. This word has come to represent an array of different production and inventory control systems which signal when to replenish material. Kanban systems utilize a substitution order format (pull format) – ordering new material to replace material recently consumed. Kanban cards are used to control material flow between upstream and downstream process. These kanban cards may actually be empty boxes, electric signals, or any other effective means of communicating a need for replenishment.48

The purpose of a kanban system is to provide a limit on inventory in the pipeline. The inventory level in a kanban system is determined solely by the number of kanban cards in the system. With a properly implemented Kanban, inventory tends to be reduced to less than 30% of the initial level while maintaining the same order fill rate, shorter lead times for customer orders, and the

same customer service level. Additionally, kanbans lead to workers being more in-control of their job and less frustrated. Three critical prerequisites to any kanban system are: leveled production; disciplined card handling; and timely reordering and deliveries.49

10.2 Business Process Reengineering Overview

Business process reengineering (BPR) involves the restructuring and transformation of a business process by fundamentally rethinking and redesigning it to achieve dramatic improvements in cost, quality, and speed. BPR was one of the most influential management movements of the 1990’s, and it put management attention squarely on operations and business processes. The ideas behind BPR were developed by Michael Hammer and James Champy in their 1993 best-selling book entitled *Reengineering the Corporation.*50

At the heart of process reengineering is the idea of discontinuous thinking, leading to the recognition and breaking away from the outdated rules and fundamental assumptions that underlie operations. While continuous improvement takes a process toward ideal performance in regular, incremental steps, reengineering is needed occasionally to make a radical change. Typical drivers for radical changes are generally external and due to dramatic changes in customer expectations or a change in technology that makes possible a completely different process design. BPR emulates the ideas of discontinuous change with the four general themes of a process orientation, a creative use of information technology, ambition, and rule-breaking. Reengineering teams approach existing processes with the questions of “why?” and “what if?” and create new processes, facility layouts, and organizational structures that provide dramatic levels of operational and performance improvements.49

10.3 Materials Delivery Process for Twintec Plates

At the onset of the internship, one of the most challenging, complex, and laborious of the materials delivery processes was that of the Twintec plates. These 384-well Twintec plates are used in Core Sequencing Production to carry 384 distinct DNA segments per plate, and in a typical day approximately 1600 of these Twintec plates are consumed. The two major factors that were driving complexity in the materials delivery process for these plates were: 1) each plate was labeled with one of 72 possible color-codes for easy visual identification of which process steps a particular plate was supposed to go through; and 2) it was necessary to forecast the future consumption of each of the 72 different color-coded plate types.

From a very high level, the materials delivery process for Twintec plates is as follows: Broad receives unlabeled Twintec plates from their supplier; Broad receives color-coded barcodes for the plates from another of their suppliers; the Twintec plates are labeled by the Supply and Quality Management Group with color-coded barcodes by using a piece of automated labeling equipment; the labeled plates are then delivered to the Core Sequencing Group where they are subsequently consumed. While this does not sound like an overly complex process to manage, due to the sheer number of possible color code combinations and the inherent inaccuracy of any

50 Source: Vokoun, Matthew, “Operations Capability Improvement of a Molecular Biology Laboratory in a High Throuput Genome Sequencing Center.”
forecasting system, Broad's Supply and Quality Management Group was devoting significant labor resources to maintaining the system while holding excessive levels of plate and label inventories. All in all, this system required approximately three man-hours per day of SQMG labor resources and resulted in on-site plate and label inventories of $205K and $204K, respectively. These inventory levels represent inventory turnovers of roughly 8.7 weeks for the plates and 6.3 years for the labels. See Figure 11 for a detailed process flow map of the original Twintec plate delivery process.

With the goal to reduce labor requirements and inventory levels associated with the Twintec plate delivery process, some aspects of lean manufacturing and business process reengineering were utilized. First, the color code scheme was evaluated by a team of Core Sequencing employees and through a rationalization process the number of possible color codes was reduced from 72 to 9. Second, once the color code change was implemented on the production floor, the need for forecasting and other non-value-adding activities were eliminated through the implementation of a kanban system for the labeled Twintec plates. The kanban cards used in this system are bins which are emptied by Core Sequencing as plates are consumed and the empty bins are then placed in designated areas where they are picked up and filled with freshly labeled plates by Supply and Quality Management employees. The pick-up and return of these bins is scheduled at two designated times per day.

The result of these two improvement efforts (color code reduction and kanban implementation) had significant results in the form of labor and inventory reduction. Specifically, the new plate delivery system is estimated to save roughly 2.5 man-hours per day (with 1 hour of savings from
the elimination of travel and counting requirements for SQMG employees and another 1.5 hours of savings from the elimination of breaking down boxes and forecasting for Core Sequencing employees). Additionally, inventory levels of plates and labels are reduced by approximately $70K and $100K, respectively (the reduction of plate inventory is a direct savings, while the reduction in label inventories represents the obsolescence of a number of labels due to the new color code system). Figure 12 provides a detailed process flow map for the new Twintec plate material delivery process.

![Figure 12. Process Flow Map of New Twintec Plate Delivery System.](image)

The old Twintec plate delivery process is merely one example of a materials delivery process at Broad that could be improved through the implementation of lean and business process reengineering techniques. If the Supply and Quality Management Group is dedicated to pursuing further employee productivity increases and reducing inventory levels then the lessons learned from this successful implementation will be particularly valuable.

### 10.4 Quality Management of Agar Plates

Many of the quality management systems in the Supply and Quality Management Group are primarily classified as “inspecting quality into the process.” This statement refers to enforcing quality through post-processing inspections rather than through proactive process control techniques for preventing quality issues from occurring in the first place. One clear example of this is the SQMG’s process for making the agar plates that, as described in section 1.1.1, are used in the Molecular Biology sub-process for growing cell colonies to replicate plasmids of the DNA sample being sequenced.

One potential quality defect related to agar plates is contamination – contamination in the form of unwanted organisms that, even in the presence of an antibiotic, can grow to be cell colonies on the agar plates. These unwanted organisms grow alongside the competent bacteria, and the colonies formed by these unwanted organisms may be indistinguishable (at subsequent processing steps) from the colonies formed by competent cells. In other cases, contaminated agar plates may be visually identifiable and thrown away, yet still at the significant expense of lost
labor and materials. In any case, it is of critical importance that the agar plates delivered to the Molecular Biology Production Group are contamination-free.

While the Supply and Quality Management Group does have in place certain quality-focused protocol to limit agar plate contamination levels, its primary method for ensuring quality is through multiple inspections of each plate. Once an agar plate is made the plate is inspected a minimum of three times before it is ever used in by the Molecular Biology Production Group. For the first inspection, plates are stored in a materials “warm” room for two days and then inspected. The reasoning behind putting the plates in the “warm” room is to allow any organisms to grow if there are any present – and if any plates are contaminated then they will be removed and thrown away. After this first inspection, the plates are moved to a materials “cold” room where they remain until they are needed to replenish inventory in the production “cold” room. The plates are inspected a second time before they are moved to this production “cold” room, where molecular biologists then take the plates and inspect each plate a third time prior to spreading cells onto them. Any contaminated plates that are not caught in these three inspections will result in significant costs to Broad as these contaminated plates are used in subsequent sequencing processes. See Figure 13 for a process flow map for the entire process of producing and inspecting agar plates.

![Figure 13. Process Flow Map of Agar Plate Production and Inspection Process.](image)

According to Taichi Ohno’s seven classifications of waste, the established process flow for the agar plates incorporates several wasteful activities, most notably of which is the production of contaminated plates, relatively high inventory levels of plates due to the several stages of inspection buffers, and non-value-adding labor requirements due to multiple inspections and movement of the plates. Further, the current process does not even entirely eliminate the problem of “post-spreading” contamination of agar plates, as various levels of contaminated plates continue to be observed within the Molecular Biology Production Group (although it is not entirely clear whether all this contamination is caused by the Molecular Biology Group itself, or a small level of contaminated plates that make it through all the inspections, or a combination of both).
In an attempt to eliminate these various forms of waste, some concerted efforts were made to improve the quality of the plate production process and thereby eliminate the need for plate inspections and related activities. The potential carriers of the organisms that cause agar plate contamination are people and/or untreated air. Thus, the focus of the contamination reduction efforts was to minimize the exposure of the agar plates to these two potential carriers. In the September timeframe of the June to December internship, some initiatives were undertaken to eliminate these environmental factors through the purchase and use of a clean-room laminar flow hood for plate pouring, installation of new HEPA filters in the ceiling of the plate pouring room, face masks for employees handling the plates, and more frequent cleaning and disinfecting of the plate pouring room. Unfortunately, the contamination problem proved to be non-trivial to solve. The sum of the activities undertaken did not seem to produce the desired result of reducing or eliminating contamination from the plate production process, as contamination levels pre and post the changes were statistically equivalent.

Based on these results, the question is: how costly is the problem of plate contamination to the Supply and Quality Management Group, and how should this problem continue to be addressed? The costs associated with plate contamination can be broken up into two major categories: 1) labor costs due to time spent inspecting and transporting plates; and 2) materials costs of contaminated plates that are thrown away. Assuming a labor rate of $25 and a weekday requirement of 1.5 man-hours to inspect and transport plates, the annual labor cost is approximately $7500. In all of 2005 there were a combined total of 325 contaminated agar plates found in the two inspection steps conducted by SQMG employees and, at a cost of $6 per plate, the total annual materials cost is approximately $2000. Thus, the combined labor and materials savings that would be achieved by solving this problem are roughly $9500 per year. This relatively small amount of savings does not warrant drastic changes such as purchasing a multi-thousand dollar automated plate pouring machine, nor constructing a clean room such as one that may exist in a semiconductor fabrication plant.

Most world class manufacturing organizations, especially those that prescribe to Lean Manufacturing principles, would attempt to solve a problem of this magnitude by arming frontline workers with the capabilities to solve the problem themselves. Because nearly all manufacturing organizations have tens, if not hundreds, of inefficient and wasteful activities according to Taichi Ohno’s seven classifications of waste, arming those employees closest to the problem with process improvement capabilities can add up to substantial results when the aggregate sum of their efforts is considered. The lack of 100% employee participation in continuous improvement efforts leaves a large number of relatively small opportunities left on the table that the higher skill employees do not find time to address. The most effective and admired manufacturing organizations arm 100% of their employees with the necessary incentives and training to solve these types of problems, which ultimately leads to a real competitive advantage.

10.5 Inventory Policies for Raw Materials

The primary responsibility of the Supply and Quality Management Group at Broad is to manage the raw materials used by the genome sequencing production groups. This responsibility entails managing the ordering, receiving, stocking, and delivery processes for literally hundreds of different raw materials from over fifty different suppliers. One very important aspect of
managing this complex system is to set appropriate inventory policies that strike the right balance between inventory levels, customer service levels, and operational costs.

Broad’s current inventory policies are based on heuristics, which has resulted in a set of sub-optimal inventory policies with some room for improvement. This section describes an analytical approach for determining better inventory policies – an approach that promises to improve Broad’s performance by reducing inventory levels, increasing customer service levels, and reducing operational costs.

10.5.1 Continuous Review Re-Order Point Policy

An inventory policy for a given material can be broken up into two components: a re-order point policy and an order quantity policy. The re-order point policy tells the inventory coordinator “when” to place an order for a given material while the order quantity policy tells “how much” of that material to order.

In establishing a re-order point policy, one important decision is to determine how often inventory levels will be reviewed. The two choices are either: 1) reviewing the levels periodically (weekly, monthly); or 2) reviewing them continuously. Due to the widespread use of an ERP system at Broad, the cost associated with reviewing its raw materials inventory levels is low. Due to these low review costs, the Supply and Quality Management Group typically reviews its levels daily, which is essentially a continuous review for the purposes of choosing the appropriate re-order point model to use. Thus, the author has chosen to focus on optimizing Broad’s current inventory system which lends itself to an analysis based on a continuous review inventory model.

The expression for the re-order point (ROP) under continuous review is the following:

\[ \text{ROP} = \mu + I_s \]

where,

\[ \mu = RL \]
\[ I_s = z\sigma \]

and,

\(\mu\) = cycle stock
\(I_s\) = safety stock
\(R\) = average demand per period (day, week, or month)
\(L\) = lead time in number of periods
\(z\) = a multiplier of the standard deviation of consumption during a lead time period (corresponds to a specified service level)
\(\sigma\) = standard deviation of demand during a lead time period

The re-order point expression has two terms: 1) cycle stock; and 2) safety stock. The cycle stock is the amount of inventory that must be held during the lead time of the material in order to service average daily demand. The safety stock is the amount of inventory that needs to be held
to buffer against daily demand fluctuations about the average. In order to calculate the re-order point for a given material, historical data from Broad’s ERP system can be utilized to determine appropriate values for the average demand per period (R), the lead time of the material (L), and the standard deviation of demand during a lead time period (σ). Because the form of the re-order point expression in (4) does not include any consideration of lead time variance, a conservative approach is to use the maximum historical value for lead time (L) rather than the average value. While R, L, and σ can be calculated using historical ERP data, the appropriate value of z must be chosen based on customer service level considerations.

Assuming normally distributed daily demand, the z value determines the number of standard deviations of protection that the safety stock will cover. The z value corresponds to a desired customer service level, where “customer service level” refers to the probability that demand can be filled from inventory on any given day. Typical z values and the corresponding customer service levels are shown in Table 11. For example, a z value of 1.0 means safety stock protection of one standard deviation above the average (μ) which corresponds to a customer service level of 84.1%.\(^{51}\)

<table>
<thead>
<tr>
<th>z value</th>
<th>Customer Service Level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>84.1</td>
</tr>
<tr>
<td>1.04</td>
<td>85.0</td>
</tr>
<tr>
<td>1.28</td>
<td>90.0</td>
</tr>
<tr>
<td>1.65</td>
<td>95.0</td>
</tr>
<tr>
<td>2.33</td>
<td>99.0</td>
</tr>
<tr>
<td>3.00</td>
<td>99.9</td>
</tr>
</tbody>
</table>

An optimal customer service level (and corresponding z value) should balance the benefits of improved service in terms of supply continuity with the additional costs of holding required safety inventory. While analytical approaches such as the “newsvendor problem” can be used to determine the optimal service level for each material given these supply continuity and inventory holding cost considerations, a less sophisticated and more practical approach is to set a generic service level for all materials. For an operation such as Broad’s that requires a high level of service, choosing 99%, or z = 2.33, is typically a reasonable number.

10.5.2 Order Quantity Policy

As the re-order point for a given material is reached, Broad’s inventory coordinator must choose a new quantity of the material to order. The theoretical optimum order quantity can be derived using calculus to determine the order quantity that optimally balances the costs of holding inventory with the benefits of economies of scale. Typically, economies of scale arise from a fixed-cost component in the ordering cost, while inventory holding costs are associated with the capital cost of money, the cost of storage, and under certain circumstances the cost of obsolescence and depreciation.

The total annual inventory holding cost and ordering cost is given by:

---

\(^{51}\) Source: Anderson, James, “Automation of Inventory Management.”
(7) Total annual cost = holding cost + ordering cost

or,

(8) \[ C = \frac{HQ}{2} + \frac{PA}{Q} \]

Taking the first derivative of (8) with respect to order quantity, \( Q \), yields:

(9) \[ \frac{dC}{dQ} = \frac{H}{2} - \frac{PA}{Q^2} \]

Setting the first derivative in (9) to zero (a condition to minimize \( C \)) and solving for \( Q \) yields:

(10) \[ Q^* = \sqrt{\frac{2PA}{H}} \]

where,

- \( C \) = total annual cost
- \( Q \) = order quantity
- \( A \) = annual demand for the units
- \( M \) = unit cost (no holding or order costs included)
- \( H \) = inventory holding cost per unit (capital, storage, obsolescence, depreciation)
- \( P \) = cost to prepare order for \( Q \) units

In order to use the expression (10) to calculate the optimal order quantity for a given material, appropriate values for the variables \( P \), \( A \), and \( H \) must first be determined. For Broad, the cost associated with preparing an order (\( P \)) is determined by estimating and summing the following costs: preparation of a purchase order; the labor associated with actually receiving each order; and for certain materials the cost associated with performing any quality assurance tests for a batch of that material. The annual demand (\( A \)) is determined by calculating historical consumption based on data in Broad’s ERP system. The inventory holding cost per unit of a given material (\( H \)) is typically calculated as a percentage of the value of each unit and includes considerations of: 1) the capital cost of money; 2) storage costs; 3) obsolescence; and 4) depreciation. One common rule of thumb is to use a holding cost percentage of 12% by default, which assumes obsolescence and depreciation are negligible. Adjustments to this generic holding cost percentage may be necessary on a case by case basis in order to account for certain materials properties such as large sizes, special storage conditions, obsolescence, etc.

### 10.5.3 Perishable Inventory Considerations

A number of materials used at Broad have shelf lives as specified by the manufacturer or as determined by Broad’s scientists. For these perishable materials, the inventory policies described above may lead to sub-optimally large purchase order quantities that result in a significant
amount of material expiring. For materials with shelf lives, additional considerations are necessary to calculate the optimal order quantities.

There is a significant amount of operations research literature devoted to perishable inventory theory. However, the models derived for stochastic (uncertain) demand with fixed product lifetimes are typically quite complex. The complexity of these models favors a more practical, heuristic approach, which is described below.

Given a perishable material with a fixed shelf life, the optimal order quantity is the quantity determined from expression (10) only if that order quantity does not result in units of the material expiring. Thus, the optimal quantity \( Q^{**} \) for a perishable material is the following:

\[
Q^{**} = \min(Q^*, R'm)
\]

where,

\[
R' = \text{average demand per period (day, week, or month)}
\]
\[
m = \text{the shelf life of the material (day, week, or month)}
\]

Because demand for the material is assumed to be stochastic (uncertain), the value used for \( R' \) should be a conservatively low estimate of what the future demand will be. The actual calculation for \( R' \) could entail subtracting some multiple of standard deviation from the historical average demand for the material.

### 10.5.4 Expected Benefits of Improved Inventory Policies for Stockroom Materials

The Supply and Quality Management Group separates its raw materials into two categories: stockroom materials and chemical stockroom materials. Stockroom materials are typically solid, shelf-stable materials, while chemical stockroom materials may be solid or liquid with special storage requirements, quality assurance tests, and/or expiration dates. For the sake of yielding some insight into the potential benefits of applying the inventory policies described above, a simple analysis of Broad's stockroom materials inventory policies is presented below.

The benefits of incorporating the analytic inventory policies for Broad's stockroom materials can be described in terms of average inventory on-site as well as total annual operating costs (including inventory holding and ordering costs). Based on the key assumptions of a cost per order of $100, inventory holding costs of 12%, additional holding costs for large objects at $40 per square foot, and a desired customer service level of 99%, the following comparison can be made (see Table 12):

---

52 Source: Nahmias, Steven, "Perishable Inventory Theory: A Review."

<table>
<thead>
<tr>
<th>Inventory Policy</th>
<th>Average Inventory On-Site</th>
<th>Annual Inventory Holding Costs</th>
<th>Annual Ordering Costs</th>
<th>Total Annual Costs (Holding plus Ordering)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual (Current)</td>
<td>$524K</td>
<td>$63K</td>
<td>$187K</td>
<td>$250K</td>
</tr>
<tr>
<td>Analytic (Proposed)</td>
<td>$419K</td>
<td>$50K</td>
<td>$30K</td>
<td>$80K</td>
</tr>
<tr>
<td>Difference (Manual – Analytic)</td>
<td>($105K)</td>
<td>($13K)</td>
<td>($157K)</td>
<td>($170K)</td>
</tr>
</tbody>
</table>

The potential benefits are clearly significant. The prescribed analytic inventory policies would reduce on-site inventory of stockroom materials by an estimated $105K, while reducing total annual operating costs by $170K per year. This represents reductions of 20% and 68% for on-site inventory levels and total annual costs, respectively. Similarly significant benefits would be expected from implementing these analytic inventory policies for chemical stockroom materials as well.
11 Conclusion

The Genome Sequencing Group’s goal to achieve higher levels of organizational performance is driven by its fundamental desire to provide significant societal benefits. Further improvements in the cost to sequence a genome will eventually open the door for every person to have his or her own genome sequenced, enabling the critical data needed for the personalized medicine vision. Additionally, efficiency gains in genome sequencing also promise to help address the rising costs of developing new drugs.

Broad’s Genome Sequencing Organization has already provided society with significant benefits through achieving a cost leadership position in the genome sequencing industry. Broad has achieved its leadership position primarily through its ability to rapidly implement and continuously improve new and more-efficient, industrial-scale process technologies. While the capability to develop and implement process technology improvements is one critical aspect towards achieving higher levels of performance within the genome sequencing industry, another critical aspect which has received less attention is the ability to make operations-related improvements.

In countless industries, world-class manufacturing organizations have shown that a large portion of productivity and performance improvements can take the form of an accumulation of operations improvements driven by employees at all levels of the organization. These world-class manufacturing organizations have achieved and sustained leadership positions in their highly competitive industries through using their operations capabilities as competitive weapons.

Since 1999, Broad’s Genome Sequencing Group has sponsored several LFM internships as part of the group’s long-term investment to improve the operations capability of its workforce. Through exposure to LFM interns and their projects, a large number of employees at Broad have learned of various operations management tools – tools that were used to improve some aspect of Broad’s operations during the course of the LFM internships. Yet, despite its leadership position within the genome sequencing industry, Broad’s operations capability is still underdeveloped compared to world-class manufacturing organizations.

This thesis presents two proven management techniques that would allow Broad’s Genome Sequencing Group to further develop its operations capability to achieve more significant performance improvements: 1) performance measurement and 2) process approach. This chapter highlights these two management techniques and ties together the discussion of the preceding chapters to provide some recommendations for future work.

11.1 Performance Measurement

This thesis introduces a proven management technique – performance measurement – which would effectively catalyze the development of Broad’s operations capability to achieve higher and higher levels of performance. The performance measurement system proposed in this thesis would provide new incentive mechanisms and accountability of results for employees at Broad.

Without the appropriate incentive mechanisms in place, it is unlikely that Broad will develop into an operationally excellent organization, even if Broad’s managers continue to provide
employees with training opportunities and exposure to LFM-intern-led projects. The performance measurement system designed for Broad’s Genome Sequencing Group and presented in this thesis is based on the state-of-the-art Balanced Scorecard methodology that has found widespread usage in for-profit and not-for-profit organizations alike. Although the benefits of implementing a performance measurement system are “soft” and do not lend to an objective return-on-investment analysis, subjective evidence from other organizations indicates that performance measurement systems do yield significant positive results that dwarf any up-front investment. A Balanced Scorecard performance measurement system would facilitate the transformation of Broad’s Genome Sequencing Group into a higher-achieving, operationally excellent organization.

The first phase of a Balanced Scorecard implementation project at Broad would require a team of five or six part-time members and one dedicated leader over a six-month time period. During the timeframe of this internship, Broad was undergoing several organizational changes and did not have the organizational bandwidth for yet another change initiative such as implementing a performance measurement system. One potential option is to assign this project to a future LFM intern; this project has the appropriate duration and scope to serve as an excellent opportunity for an intern during the next LFM internship cycle.

11.2 Process Approach

This thesis also presents some of the work completed during the course of the six and a half month internship. The theme of this work is a process approach that leads to higher levels of organizational performance. World-class manufacturing organizations achieve desired results by managing their activities in well-defined, efficient processes. Applying the principle of process approach at Broad led to some increased organizational efficiencies through systematic improvement of various processes and the elimination of non-value-adding activities.

The internship touched on four important processes within the Supply and Quality Management Group: materials change management, materials delivery; quality management, and inventory management. Based on the results and analyses presented in this thesis, it is clear that Broad’s Supply and Quality Management Group (and the Genome Sequencing Group as a whole) could achieve significant performance improvements with respect to its common business activities through a process approach and the application of lean and business process reengineering tools.

Perhaps the most tangible results of this internship were seen through the various initiatives to improve the materials delivery process for Twintec plates as described in section 10.3 of this thesis. By reducing the number of possible plate color-code combinations from 72 to 9 and subsequently implementing a kanban system, a $70K plate inventory reduction was achieved and labor savings of approximately 2.5 man-hours per day were realized. It is clear that the employees at Broad have the necessary skillsets to improve operational performance through pursuing process improvement initiatives like those described in chapter 10 – the implementation of a performance measurement would help motivate them to take these initiatives.
12 Bibliography


13 Appendix – Materials Change Management Documents

The Broad Institute – DNA Sequencing Operations
Materials Change Control Form (Rev 0.0)

i. Originator:

ii. Date:

iii. Change Title:

iv. Change Description:

<table>
<thead>
<tr>
<th>#</th>
<th>Change Item</th>
<th>Present</th>
<th>Proposed</th>
</tr>
</thead>
</table>

v. Change Classification Level:

a) Type:
   [ ] Preliminary (seeking approval to qualify a change)
   [ ] Final (seeking approval to fully implement a change)

b) Level:
   [ ] Level I (low risk)
   [ ] Level II (medium risk)
   [ ] Level III (high risk)

vi. Reason for Change:

a) Expected benefits of the change (include any impacts to safety, quality, cost, labor, and/or throughput):

b) Estimated cost to qualify and implement the change:

vii. Additional Impacts:

<table>
<thead>
<tr>
<th>#</th>
<th>Potential Impact</th>
<th>Yes/No*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Environment/Safety</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Automation</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Equipment Maintenance</td>
<td></td>
</tr>
</tbody>
</table>

*For each “yes” answer, the appropriate Broad employee must be added as a reviewer to the change control form.
### Potential Failure Modes and Risks:

<table>
<thead>
<tr>
<th>#</th>
<th>Issue</th>
<th>Resolution</th>
<th>&quot;Status (Open or Closed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*All potential failure modes and risks should be resolved before a "Final" change control form is approved.

### Preliminary Data:

**a) Summary of DOE(s):**

| Design description: Screening, Characterization, Optimization, Process Window |
|---|---|---|---|
| Resolution: III, IV, V, full, or N/A |
| Response | F-statistic(s) | R² values(s) | p-Value |
|   |   |   |   |

**b) Summary of data:**

<table>
<thead>
<tr>
<th>Response</th>
<th>Baseline (avg ± lo: # runs meas)</th>
<th>New process (avg ± lo: # runs meas)</th>
<th>0-type (p-p: individual)</th>
<th>New process outliers?</th>
<th>New process decision (better/worse/no change)</th>
<th>Data date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

0-type: p-p=stdev of plate means, indiv=stdev of raw data.  
Data date indicates dates experiment in progress. Example: 7/5/05 to 7/9/05

### Pilot Data:

**a) Pilot plan description:**

<table>
<thead>
<tr>
<th>Operational Description</th>
<th>Product</th>
<th># Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**b) Data to be collected:**

<table>
<thead>
<tr>
<th>Response</th>
<th>Exp’t Type</th>
<th># Runs</th>
<th># Samples per Run</th>
<th># Days</th>
<th>0 or λ Sensitivity</th>
<th>Success Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exp’t Type: N/A (gross reality check). 1 sample, 2 sample, 2 sample paired (split).  
# Samples per Run: Describe what your sample is (number of plates, number of wells/plate and location, etc.).  
0 or λ Sensitivity: Determined by # Runs, Exp’t Type, and risks fixed at α = 0.05, β = 0.05. Note that 1-5 runs are gross reality checks with 0, λ = N/A.

**c) Summary of data:**

<table>
<thead>
<tr>
<th>Response</th>
<th>Baseline (avg ± lo: # runs meas)</th>
<th>New process (avg ± lo: # runs meas)</th>
<th>0-type (p-p: individual)</th>
<th>New process outliers?</th>
<th>New process decision (better/worse/no change)</th>
<th>Data date</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

0-type: p-p=stdev of plate means, indiv=stdev of raw data.  
Data date indicates dates experiment in progress. Example: 7/5/05 to 7/9/05
### Implementation Plan:

<table>
<thead>
<tr>
<th>Action</th>
<th>Owner(s)</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicate the change to the appropriate operators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Update relevant protocols and the bill of materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Announce the change at the all-hands meeting</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Reviewers:

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Level I: A change that does not represent a fundamental change to the process technique or material components and does not have any significant potential failure modes associated with it. These changes typically require no formal qualification.

Examples
- Manual pipette tips

Level II: A change that does not represent a fundamental change to the process technique or material components but does have one or more significant potential failure modes associated with it. These changes will typically require a formal qualification plan to prove equivalent or improved performance as well as to mitigate risk.

Examples
- Greiner plates (new supplier manufacturing site in North Carolina)

Level III: A change that does represent a fundamental change to the process technique or material components. These changes require a formal qualification plan to prove equivalent or improved performance as well as to mitigate risk.

Examples
- Competent cells (new cell/cuvette combination)
The Broad Institute – DNA Sequencing Operations
Materials Change Approval Process (Rev 0.0)

1. Start with posted Materials Change Control Form template.
2. Consult with process/materials expert(s) early on to determine potential failure modes and risks associated with the proposed materials change. Include all of the identified potential failure modes in section viii (Potential Failure Modes and Risks) of the Materials Change Control Form.
3. Classify the change according to the posted Materials Change Classification Guidelines. (Note: if there is any disagreement about the correct classification level for a given change, it is typically best to take the more conservative approach.)
4. Complete the Materials Change Control Form.

Reviewers:
The review of Materials Change Control Forms should be conducted in the following order for each change classification level (note: if a revision to the form is made at any time during the approval process, judgment is required to determine if the form should be reviewed a second time by a person who has already reviewed it once):

Level I:
1. All supervisors whose areas will be impacted by the change.
2. Per section vii (Additional Impacts) of the Materials Change Control Form, any additional Broad employees who need to be aware of the change.
3. All managers whose areas will be impacted by the change.
4. Anyone who is listed as an owner in section xi (Implementation Plan) of the Materials Change Control Form.

Level II:
1. All supervisors whose areas will be impacted by the change.
2. All managers whose areas will be impacted by the change.
3. Per section vii (Additional Impacts) of the Materials Change Control Form, any additional Broad employees who need to be aware of the change.
4. Anyone who is listed as an owner in section xi (Implementation Plan) of the Materials Change Control Form.
5. Process expert from the technology development group.
Note: A meeting is typically the best forum for reviewing Level II and III changes.
Level III:
1. All supervisors whose areas will be impacted by the change.
2. All managers whose areas will be impacted by the change.
3. Per section vii (Additional Impacts) of the Materials Change Control Form, any additional Broad employees who need to be aware of the change.
4. Anyone who is listed as an owner in section xi (Implementation Plan) of the Materials Change Control Form.
5. Process expert from the technology development group.
6. Director of Sequencing Operations.

Note: A meeting is typically the best forum for reviewing Level II and III changes.
The Broad Institute - DNA Sequencing Operations
Materials Change Process Map (Rev 0.0)

Start

Identify change opportunity in materials

Process/talespiined (as necessary) identify potential new routes and basic requirements. The Materials Management department provides support.

Approach material according to the change management guidelines

Organizer fills out "Final" Change Control Form

Organizer routes "Final" Change Control Form through Level I and Level II process review. Changes are necessary changes to the form

Approve?

Yes

No

End

Classification Level? Level I

Organizer fills out "Temporary" Change Control Form

Organizer routes "Temporary" Change Control Form through Level I and Level II process review. Changes are necessary changes to the form

Approve?

Yes

No

End

Classification Level? Level II

Organizer fills out "Temporary" Change Control Form

Organizer routes "Temporary" Change Control Form through Level I process review. Changes are necessary changes to the form

Approve?

Yes

No

Organizer fills out Change Control Form to submit new and/or amended policy and procedures.