The Complete Guide to Mixed Model Line Design

Designing the Perfect Value Stream

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The Complete Guide to Mixed Model Line Design
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Table of Contents

Acknowledgments viii

Foreword ix

Is This Book For Me? x

CHAPTER 1 Introduction 13

Is Line Design New? 13
Execution Is Key 14
Main Line Design Benefits 15
Lessons Learned 17

CHAPTER 2 What Is Lean? 19

What Is Flow Processing? 21
Why Do Companies Use Lean? 22
Operational Benefits 24
Discrete Manufacturing 25
Process Manufacturing 26
Lessons Learned 28

CHAPTER 3 Assessment & Preparation 31

Business 101 31
Lean Preparation 35
The Process Maturity Model 37
The Value Stream Maturity Model 39
The Lean Assessment 41
Lessons Learned 41

CHAPTER 4 Selecting a Target Area 43

Value Stream Mapping 44
VSM Cautions 51
Selecting a Target Area 53
Creating A Lean Master Plan 55
Lessons Learned 56

CHAPTER 5 Understanding the Flow 57

What Is A Process? 57
The Preliminary Product List 58
The Process Flow Diagram 59
Is Queue Time Included? 62
CHAPTER 10 Resources 117
Resource Calculations 118
Weighted Average Standard Time 120
Final Resource Calculations 122
Manufacturing Cells 122
Using Resource Calculations 124
Lessons Learned 124

CHAPTER 11 Achieving Balance 125
Mixed Model Balance 126
Balancing Workstations 127
Eliminating Waste 128
Relocating Work 129
Adding Resources 130
Adding In-Process Kanbans (IPKs) 130
Adding Inventory Plus Time 131
Sequencing 133
Creating Machine Cells 134
Overcoming Changeovers 135
The Self-Balancing Line 138
Balancing With Options 139
Balancing Work With POLCA 140
Lessons Learned 141

CHAPTER 12 Line Layout 143
Connecting Processes 144
Tool 1: Direct Connect 144
Tool 2: In-Process Kanbans 146
Tool 3: FIFO Lanes 147
Tool 4: Kanban Direct 149
Tool 5: Kanban Supermarket 151
Workstation Definition 152
Preliminary Layout Notes 155
The CAD Layout 156
Beyond the Layout 156
Lessons Learned 157

CHAPTER 13 Simulation Modeling 159
Why Simulation? 159
Case Study One: The Value of Simulation 160
Spreadsheets and Simulation 161
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To our hospital clients, for the opportunity to apply Lean methods in an entirely different industry. Special thanks to the dedicated Lean teams at Orange Regional Medical Center, Exempla Good Samaritan, Riley Children’s Hospital, and White Plains Hospital.
When we published *Fundamentals of Flow Manufacturing* in 2002, we asked our readers to focus on the tools and techniques of Lean Manufacturing, and proposed a way to successfully implement Lean without a “one size fits all” recipe. Times change, and we have evolved based on our acquired knowledge. This new book, *The Complete Guide to Mixed Model Line Design*, asks our readers to expand their focus beyond the Lean tool set to the ever-important issue of sustaining the benefits gained through the implementation of Lean Manufacturing and Lean techniques. This approach, which we call The Lean Roadmap, is the result of the years of accumulated experience in the authors’ training and consulting practices.

As you read this new book, you will find some familiar material. After all, the tool set proposed originally in *Fundamentals* is truly fundamental, and will withstand the test of time. You will also find a lot of new material, including five major additions:

**Additional Content.** More on line design, standard work, line design optimization, and simulation modeling.

**The Lean Roadmap.** This content is based on the pressing need in the world of process improvement to sustain the benefits gained from the implementation
of Lean Manufacturing. Included in this discussion is a special emphasis on the importance of Lean leadership and the creation of a formal Lean Management System. The Lean Roadmap will allow you to plan, assess, and sustain your journey in a precise way. The Roadmap itself, in a check list format, is included as Appendix I in this book.

**The Value Stream Maturity Model.** We are introducing a method for assessing the maturity model of an entire Value Stream, which is made up of many individual processes. The Value Stream Maturity Model will be necessary and helpful in measuring your progress.

**Memory Joggers.** For serious readers, an exciting addition to this book is the opportunity to test your understanding and gained knowledge with a follow-up reminder program. By successfully viewing and completing a quick weekly mini-lesson, you can keep your Line Design knowledge fresh. The Memory Joggers are an additional incentive for Lean practitioners to give *The Complete Guide* a careful read.

**Simulation Modeling.** It has been clear for a long time that the complexities of a mixed model line make them difficult to understand or test during the design phase. Often the line gets tested for the first time when it goes “live”, and when improvements and changes are necessary. It is cheaper and much easier to test the proposed line performance using computer simulation, and the tools of simulation modeling have made this accessible for most companies. We have added a chapter on this important topic.

**Is This Book For Me?**

This book covers all of the essential steps and sequence of activities to achieve both a successful Line Design implementation, and sustainability of the benefits gained from the introduction of these Lean techniques in the factory or office.

We have seen and heard of many cases where, after a successful series of Lean Manufacturing projects, the benefits are frittered away due to a change in management, employee turnover, lack of ownership, lack of training and a host of other reasons. We call this slippage or backsliding. Unless the right tools, culture and accountability are in place, your Lean gains are always at risk.

A failure to sustain Lean progress can be attributed to a lack of knowledge and accountability in the management ranks. Sometimes, managers do not know what to look for, or what questions to ask, when it comes to the progress of their Lean projects. If called upon, many managers could not teach the subjects they are ostensibly responsible for. *The Complete Guide to Mixed Model Line Design*
will help you put in place the necessary elements, from training to management dashboards, to ensure that you can sustain your Lean accomplishments a year from now, five years from now, and beyond. It documents how to design a linked and balanced Value Stream, based on customer demand, with a focus on achieving optimum cycle time or response time, and is a guide to the most important characteristics of a Lean enterprise.

We look forward to hearing from you, and hope that you’ll share your Line Design journey with other readers. Enjoy!
Chapter 1 Introduction

The toolkit of Lean methods and techniques is extensive and powerful. Lean practitioners in manufacturing and other industries are already familiar with Lean tools like 5S, Quick Changeover, Value Stream Mapping, Standard Work and Kaizen. There is one critical skill that many Lean professionals don’t know: Line Design. We are referring to more than a common-sense approach to designing a Lean process, where you arrange the work-flow logically to reduce waste. It is Lean Industrial Engineering, a step-by-step methodology for designing an optimum Value Stream. This skill is the most important tool in the Lean toolkit, since optimum process design is the source of the majority of Lean benefits. Most Lean professionals and managers don’t have this skill, a lack we will remedy in this book and in our other training options.

Is Line Design New?

When you find the word Complete in a book title, your skepticism warning siren goes off fast. We think we can back up this claim. The Complete Guide to Mixed Model Line Design is our call to revolutionize the way work is designed and performed in offices and factories, in the interest of improved competitiveness, more satisfying work, happier workers, and a growing and successful business. More than a high-level strategy statement, we will guide you through the process of how to do it.

Hasn’t this all been said before, you might ask? Isn’t this all just repackaging stuff that’s been in circulation for years, old wine in a new bottle? Lean
Manufacturing concepts have been around since the time of Frederick Winslow Taylor and Henry Ford, at the beginning of the 20th Century, and the Six Sigma approach was developed in the 1980’s. It is true that many, maybe most, companies these days have dabbled in Lean and Six Sigma methods. Some claim that Lean is their main strategic focus, and a core value. Many are doing very well with their Lean efforts, especially when compared to their previous performance. In industries such as automotive or electronics, Lean has become a competitive necessity. In these industries it is virtually impossible to be competitive without it. A look behind the curtains in most companies reveals remaining mountains of waste, inter-departmental turf wars, long lead-times and high overhead costs. This is good news, in a sense. After all, if you’ve been able to survive so far, think how much better you’ll be when you eliminate waste! Time is running out, and the question that arises is this: if Lean has been around so long, and is apparently so well accepted, why aren’t more companies mature in their Lean efforts? Why aren’t there a lot more Toyotas in the world?

There is no one answer to this quandary. Certainly leadership plays a big role. Most companies do not have Toyota’s Taichi Ohno at the helm, to lead the Lean charge and insist on unwavering commitment to improvement. Publicly-held companies, in particular, are focused on short-term results, which is quite different from the long-term strategy that is necessary. Lean leadership in too many companies is delegated to lower levels in the organization, or is seen as related to manufacturing only. The upper management team continues with business as usual.

**Execution Is Key**

Where many companies fall down is in the *execution* of their Lean initiative. Let us assume that your leadership team is fully trained and engaged, for that *is* a prerequisite. What happens next is a flurry of improvement activity based on the idea of Kaizen, or continuous improvement. If you have done some Lean homework, you also know that a first improvement step involves creating a flowchart of product families and major processes, called a *Value Stream Map*. You may have sent people to Lean training classes, and stocked a library with the latest books. What you lack is a comprehensive plan, leading to a comprehensive *design*, and a commitment to extend Lean training and engagement to your entire workforce. Most companies do not fully embrace a vision of complete process control, and do not mentor their workforce to become highly skilled problem-solvers and waste-eliminators.

The term *cycle-time* is a crucial Lean concept, for good reason. Although there are many performance benefits expected from a Lean initiative, a reduction in
cycle-time or value stream response time is our primary focus. Cycle-time through the Value Stream is directly or indirectly associated with most of the major performance benefits that you would like to achieve:

- Fast customer response
- Minimal WIP inventory
- Reduced working capital requirements
- Improved productivity
- Reduced scrap and rework
- Better utilization of available floor space
- Improved ability to respond to unplanned demand
- Increased ability to gain market share
- Ability to compete head-on with low labor cost areas of the world

This long list of benefits is a powerful reason to include cycle-time as a key performance indicator, and to structure your competitive strategy around this goal, with the confidence that other performance goals will come along for the ride.

The sub-title of this book claims that it can help you design the perfect value stream, and we will expand on this claim a bit further. You are accustomed to the notion of pursuing perfection, but perfection is something always just outside of your grasp, something that is continually receding into the future like a mirage. Let us first describe what a Value Stream is, and then list the characteristics of a perfect one. You can then judge just how close you can get to the actual state of perfection.

Main Line Design Benefits

The term Value Stream refers to the relationship of all of the processes in a flow that enables you to produce a product. A complete Value Stream begins with outside suppliers and ends with the end-user or customer, and it is therefore a start-to-finish description of the work required to deliver a product into the hands of your customers. Keep in mind that the customer may be internal as well as external, and that the product could be information, as well as a physical object. The Value Stream is documented in a flow-chart format, using specific symbols representing various tools and methods in the Lean toolkit. Whether you use the value stream mapping symbols or not, there is great value in starting your Lean journey by creating an extended flow chart that captures all of the processes required on the value stream, and how they are related in time. Much more on this later. So what would be the characteristics of the perfect value stream?
The shortest possible cycle time. By linking and balancing the processes on the value stream, you can expect the critical-path cycle time to approach the optimum. In a perfect but theoretical Lean Value Stream, work would progress from step to step with no queue time at all. In reality, if the elapsed time is within 300-400% of the critical path work content time, you are in world-class performance territory.

The best possible quality. We know that linking and balancing the flow of work results in dramatic quality improvements. This happens naturally as confusion-causing clutter is removed from a work area, and the amount of WIP is greatly reduced. In this environment, workers can focus on a few items at a time and catch mistakes, resulting in a quality boost. Workers in a Lean environment are also taught to check the work coming to them for defects, and to formally inspect their own work, with a technique known as check-do-check. Combined with single piece flow, check-do-check can greatly limit the number of defects occurring in the flow of work. Finally, great emphasis is placed on mistake-proofing the work; the Japanese term for this is poka-yoke. Six Sigma methods will be used to analyze the root cause of recurring quality issues. Our goal is zero defects.

The highest productivity. By linking and balancing the flow of work, and by mistake-proofing the process, you invariably find that you also achieve a significant productivity gain. The waste that is eliminated from the workflow translates directly into more time available to add value building products. We have rarely seen less than a 20% productivity increase.

While these benefits may not qualify as perfection, one thing is certain. By following the process documented in this book, you have a real opportunity to design a Value Stream that is unbeatable. Competitors using the same processes may be able to tie your performance, but they won’t be able to beat it. Keep in mind that until you reach a high level of continuous improvement, your improvements are vulnerable to being copied. Potential competitors can simply replicate what you have done, shorten their learning curve, and quickly become more formidable competitors. That is why it is important to quickly move to a higher Value Stream maturity level, where the workforce is continually refining the value stream through continuous small improvements as well as larger projects. When you reach this stage, it will be difficult for competitors to keep up, since the changes and improvements will be virtually impossible to replicate.

Workers arise! You have nothing to lose but your waste!
Lessons Learned

Line Design is a necessary Lean skill that many Lean practitioners don’t have. In a manufacturing environment, most of the Lean benefits will come from an optimal process design.

Line Design can be thought of as Industrial Engineering with a Lean twist. It is not something entirely new, nor is it a passing fad.

The main benefits of optimal line design include greatly reduced lead-time, high quality, and high productivity.

The subsequent chapters of this book follow a Lean Roadmap, a recommended series of steps to accomplish an optimal line design.
Chapter 2 What Is Lean?

**BENEFITS OF LEAN**

**WHAT IS FLOW PROCESSING?**

**WHY DO COMPANIES USE LEAN?**

**OPERATIONAL BENEFITS**

**DISCRETE MANUFACTURING**

**PROCESS MANUFACTURING**

The first exposure to the concepts of Lean Manufacturing is often a shock. The initial reaction is frequently “Wow!” and “Why didn’t we do this sooner?” The universal conclusion is that adopting Lean makes sense, and makes a positive difference in how you organize your work and run your businesses.

As the message spread through word of mouth, case histories, books and publications, Lean Manufacturing and flow processing methods gained a great deal of popularity during the 1990’s. Today, more than a decade later, Lean practitioners are still reporting significant, and sometimes amazing financial and performance gains. Every day, a new visionary manager realizes that the tools and techniques of Lean Manufacturing are as powerful as they are simple. The benefits realized by companies who have adopted Lean techniques usually include:

* **Inventory reduction.** It is common to see a 90% reduction in work-in-process inventory, when moving from traditional manufacturing to a Lean environment.

* **Quality improvements.** A requirement to document and standardize work, error-proof processes and focus quality at the point where work is performed, results in a dramatic decline in scrap and rework.
**Improved productivity.** Training employees to perform standard work, with a special focus on quality, results in impressive productivity gains, even in mature industries.

**Improved response time to customer orders.** In today’s world, the ability to respond quickly to a customer’s requirements is no longer a competitive advantage, but a competitive necessity. Driving out waste, in the form of queue time, allows Lean lines to make products in a fraction of the time required by traditional manufacturing methods. This is done not by working harder or faster, but by designing a process that can move from one step to another without delay.

**Reduction in the working capital needed to run a business.** The availability of working capital can be a key constraining factor, or even a cause for business failure. Lean companies dramatically drive down the need for working capital.

**Floor space and capital asset utilization improvement.** The linking and balancing of manufacturing processes together into flow lines or cells, the related reduction in WIP inventory, and a thorough housekeeping effort, typically results in a 20%+ reduction in the amount of factory floor space required.

All companies have several goals in common: the desire to achieve a competitive advantage, make a profit, and increase market share. They all know that customers expect high quality products, delivered on time, configured to their specifications. Companies know that more and more of their customers are no longer brand loyal, and seek out the supplier who can best meet their requirements for quality, delivery and price. Companies also know that in today’s global economy, competition can come from anywhere on the planet, often from low labor cost countries.

Visionary managers are not discouraged by these challenges. Rather, they see the ability to meet or exceed their customers’ expectations as a significant competitive difference. A growing number of companies are looking to Lean Manufacturing as the method to help them achieve this competitive advantage. Throughout the 1990’s, entire industries converted en-masse to Lean Manufacturing. Many companies would not be in business today, had they not embraced Lean methods.

Lean is not a new concept, and although the Lean solution is surprisingly simple, many interpretations exist as to what Lean Manufacturing is. This type of manufacturing has been described and packaged in many ways. These are just a few:
• Continuous Flow Manufacturing (CFM)
• Repetitive Manufacturing
• Quick Response Manufacturing
• Just-in-Time (JIT)
• Assembly Line Manufacturing
• Agile Manufacturing
• Toyota Production System (TPS)
• Kanban Manufacturing
• Cellular Manufacturing

What Is Flow Processing?

In a Lean Manufacturing Value Stream, products progress through the required manufacturing processes without stopping, like water in a river. Hence the term *flow* and its associated phrase *Flow Processing*.

The Mississippi River begins its journey to the Gulf of Mexico as a modest stream in northern Minnesota. Moving steadily southward, joining with small and later larger streams and rivers, the Mississippi quickly grows to between 1,000 and 2,000 feet across. Over 250 tributaries join the main river: the Ohio, the Missouri, and the Arkansas among many others. The water is in constant motion, always moving forward. The tributaries are all physically connected. Unless man intervenes with dams and water projects, the water follows in a never-stopping path. The river, therefore, is our metaphor for what we are calling Flow Processing.

If products can be built one at a time, without waiting between steps, then the elapsed time required to progress through the value stream will always be significantly less than the time required to route products through a factory in batches. Reductions in manufacturing lead-time drive many of the benefits associated with Lean Manufacturing: inventory reductions, quality improvements, productivity improvements, and floor space optimization, to name a few. It is from this ability to build a product, in a time closer to its actual work content time, that the many of the benefits of Lean Manufacturing are realized.

The goal of the Lean manufacturer is to design and create a manufacturing line capable of building different products, one at a time, using only the amount of time required to actually complete the work. Wait time, queue time, and other delays are largely eliminated. The gains in manufacturing response time are not achieved by working harder or faster, but rather by implementing the tools and techniques that connect processes together, eliminating traditional “batch and queue” production. The benefits of eliminating delays in the manufacturing
process are far greater than simply trying to speed up the actual work process itself.

The rate at which work progresses through the factory is called the flow rate, processing rate, or takt. The flow of a product is achieved by grouping and balancing all of its work tasks to a calculated time target (takt). Working with this method, a person or a machine will perform a group of tasks equal to one Takt Time worth of work. The partially completed unit is then passed to the next workstation down the line, where the next Takt Time worth of work tasks is performed. The materials progress in a flow through all the manufacturing processes until all of the required work has been completed, all the parts have been consumed, and the product is finished.

Lean manufacturers may choose to regulate the output of the line to closely match the current mix and volume of customer demand. With a flow line designed to build products at a formulated Takt Time, the Lean manufacturer has the ability to regulate the effective output rate of the line. The desired rate is identified every day based on that day’s customer orders. The rate of production is adjusted by changing the number of labor resources on the line, i.e. by adding or removing people, not by changing the physical design of the line itself. Takt Time cycles will therefore be missed or completed during the day. The number of Takt Times completed is matched to the number of units required that day. The ability to change the output rate every day, driven by changes in customer order requirements, is a powerful tool for managing productivity, work in-process and finished goods inventories.

Why Do Companies Use Lean?

During the last few decades, global manufacturers have had to achieve productivity increases, operating cost reductions, quality improvements, and shortened customer lead-times in order to stay competitive. Many companies have chosen the tools of Lean Manufacturing as a solution to these challenges. If you are a customer, products coming from Lean suppliers are delivered on time, with the highest quality, and the lowest cost.

The short answer and bottom line to the question “why do companies use Lean?” is that there are financial benefits to be realized from its adoption. The following are some examples of the benefits resulting from the implementation of Lean Manufacturing. Where would you focus first?

**Increased Productivity.** The number of units produced by a group of people in a given period of time is generally accepted as the measurement of a factory’s labor productivity. By linking and balancing the work to be performed, and by
error proofing the work processes, operators can spend more time building good products and less time on rework and delays. Also inherent to Lean Manufacturing are the continuous process improvement strategies known as Kaizen or Rapid Improvement Events. These tools systematically focus on the reduction and elimination of move time, queue time, changeover time and other non-value-added activities. By eliminating waste, production employees can spend more time building products, and productivity will improve.

Many traditional manufacturers focus on direct labor productivity as a primary performance metric. While direct labor is undoubtedly one element of product cost, for many products it is the smallest component, often less than 5%. The much larger elements of product cost are direct materials and overhead. Labor productivity improvements should be considered a by-product of Lean Manufacturing methods, resulting from a correct focus on balanced work, process velocity and elimination of waste.

During the 1990’s, many mature industries began to report impressive productivity gains. While there are multiple reasons for this, including the introduction of new technologies like the internet, the introduction of Lean Manufacturing in these industries is a primary explanation for the improvement.

**Overhead Costs.** The largest opportunities for most manufacturing companies to lower costs and improve profitability lie in the category of overhead cost reduction. Direct material costs, after all, will only be reduced if products are redesigned or the company pays less for the material. While both these options are possible, it is unlikely that significant gains can be achieved in the short term. Direct labor costs already represent the smallest portion of product cost. For many products even if magical elves built the product for free, the overall reduction in product cost would be small. What is left is the 15-25% (or more!) of product cost called overhead.

A flow factory’s operating costs are reduced as a result of the following efforts:

- Total Quality Management (TQM) activities that improve process quality, reduce scrap, rework, and warranty costs.
- Inventory reduction resulting from shortened manufacturing lead-time. Reduced inventory will have a positive impact on material handling overhead, as well as reduced obsolescence, damage, storage space, productivity, interest and taxes.
- Total Productive Maintenance (TPM) programs can result in dramatic improvements in equipment up-time, quality, changeover time and capital expenditures.
- Improved resource and floor space utilization through the elimination of waste and unnecessary inventory.
• Reduced transaction costs as a result of pulling materials to the consuming lines via multiple Kanban techniques.
• A simplified manufacturing environment that reduces the need for a high level of computer transactions, complex systems and layers of supervisory and planning support.

**Shortened Customer Lead-time.** The business world today is moving at a fast pace. Customer delivery times that were once perfectly acceptable are now regarded as painfully slow. Regular mail is now referred to as snail mail. Even two-day courier delivery is too slow for some people, and you often hear the phrase “it's gotta go overnight!”. The marketplace is expecting a significantly shorter order fulfillment lead-time than it did a decade ago. A factory that arranges its resources in a flow relationship creates, by design, a much shorter manufacturing lead-time. The shorter the manufacturing lead-time, the quicker the response to a customer order, without having to carry finished goods or work-in-process inventory.

Finished goods inventory have been used as the method to shorten customer response time. It is true that by having the products ready to go on the shelf, shipment to customers can be quick. This assumes that you have on the shelf what the customer ordered. The downside of finished goods inventory is the large amount of working capital required to establish it, the risk of obsolescence or non-moving products, storage and logistics costs. And often finding out, even with a large inventory of finished goods, that you don’t have what the customer wants. The Lean manufacturer’s focus is on reducing manufacturing lead-times to a minimum, approaching the critical path work-content time. This dramatically shorter lead-time enables the Lean company to build to customer orders directly, eliminating the need for finished goods. For customized products, of course, finished goods is not even an option.

**Operational Benefits**

Production planning in a flow line is simplified, because planning occurs only at the end-item level. Subassembly production planning is virtually eliminated by linking processes together and creating direct *feeder lines*. Multi-level Bills of Material can also be dramatically simplified or flattened, since many subassembly part numbers are no longer used or transacted against. Variable staffing levels, driven by actual customer orders, control the flow rate of the line. The daily production schedule is matched as closely as possible to the actual customer orders.

Cost accounting methods can be simplified with a Lean approach. Because the lead-time through a flow facility is consistent, repeatable, and not volume sensitive,
Activity Based Costing (ABC) can be easily introduced. Labor costs for the flow manufacturer can become elements of the overhead applied proportionally to each product. A variable overhead cost may be created to account for extraordinary conversion costs driven by the use of special machines or resources.

Production reporting in Lean Manufacturing is simple and direct. Some of the typical reports in a flow environment are:

- Actual backflush units versus planned completions. Backflush eliminates the need for excessive shop floor transactions, work order reconciliation and pick lists.
- Kanban material usage variance. Work order reconciliation is eliminated.
- Resource utilization reporting. Labor tracking at the work order level is not done, although overall productivity is still reported.

Given the long list of benefits, it is not surprising that Lean Manufacturing has become a competitive necessity for most industries. The expansion of Lean methods to non-manufacturing processes and industries, like banking, software development, health care and construction, constitute the next frontier; and it is just getting started.

It is interesting to note the domination of Lean Manufacturing techniques in many industries. As the word regarding the many benefits of these proven tools spread in the 1990's, many industries converted across the board to Lean Manufacturing. The heating and air conditioning, electronic assembly, automotive, and plumbing products industries are examples. A visit to virtually any company in these industries shows the implementation of flow methods. The reason, of course, is that they had to in order to remain competitive.

Discrete Manufacturing

Discrete manufacturing is the most common production method for the application of Lean Manufacturing. Shippable end items are usually measured in individual units. The production quantities built in manufacturing can vary from one piece to large order quantities. In contrast to process intensive factories, discrete manufacturing usually requires more people than machines.

Traditional factories usually organize resources functionally, into departments or work centers. These areas include resources, people and machines, grouped together based upon the type of work they perform or the machines that are used. Factory layout and product flow are often sub-optimal. The movement of materials between resources may be indirect, and the distances traveled by the material may be long. Because semi-finished products have to travel across departmental
boundaries, large quantities of WIP inventory tend to build up throughout the factory.

The traditional plant layout, based on a functional orientation, satisfies a requirement to collect earned hours for people and machines in departments. Little or no attention is paid to the need to balance work across resources or work centers. Each resource works independently to its own pace or beat. Individual resources do not inherently consider the ability of the preceding process to supply them, or the ability of the consuming process to consume what is being produced. The result: excess inventory in the system.

In order to replenish the material consumed, discrete batch manufacturers generally use computer generated pick-lists, lists of components and assemblies required based on the current production plan and released work orders. Customer orders or demand forecasts are entered into the manufacturing system, and the system determines material requirements based on each product’s Bill of Material. Computer generated reports call for the allocation of materials to the associated work order, shop order, or schedule. The timing of the data entry of a customer order into the system determines when the materials will be allocated to the order. This can turn into a “battle of wits” among production schedulers trying to get their orders first in line. This material allocation methodology, by its very nature, is guaranteed to cause material imbalances resulting in shortages.

Process Manufacturing

Process manufacturing tends to be highly automated. During a visit to a process-oriented factory, one of the first things you notice is the size and apparent complexity of the machinery in use. The second distinct feature is that relatively few people operate the factory. The factory layout is usually determined by the order of the processing steps required to make the products. Commonly only one type of product is being manufactured at a time, in batches or lots. The manufacturing process may be a black box, with interconnected pieces of machinery linked by conveyors or pipes.

In process-oriented factories, products are nearly always produced in units of measure that are not “each”. Typical units of measure in a process factory relate to:

- Weight (Oz., Kg, Tons)
- Linear measurements (Feet, Yards, Meters)
- Surface measurements (Square Feet, Square Yards, Square Meters)
- Volume measurements (Gallons, Quarts, Cubic Meters)
However unusual, in process factories it is possible that the shipping unit of measure may be expressed in single units. High volume environments that produce discrete products, but are highly automated, have many of the same characteristics: a series of machines linked with automatic conveyors. High volume consumer products like shampoo or soap are manufactured in this way. Products are not mixed in this environment, but rather are produced in batches or runs.

Due to the nature of the conversion methods, process manufacturers already flow their products with interconnected processes. What differentiates a process manufacturer from a true flow manufacturer is that for the process manufacturer, production quantities are almost always processed in large batches or lots, while flow manufacturers are continually striving to produce smaller lot sizes. The production lot quantities found in process industries are usually calculated based on economic order quantity logic that focuses on resource utilization. Lot sizes are sometimes simply the result of a planner’s educated guess, rather than the result of profound data analysis.

Two of the biggest challenges that process manufacturers face are equipment reliability and changeover times. Because the manufacturing environment is heavily automated and interconnected, equipment failures will shut down the entire production process very quickly. Intermittent or poorly running machines can have a dramatic negative impact on overall productive capacity. Lengthy setup times between products also drive the need to produce in large batches. After an eight hour setup, the natural tendency is to produce a large quantity of product, so you don’t have to set up again, anytime soon.

Process manufacturers obtain significant benefits from the tools of flow processing. Inventory management both at the in-process level and finished goods level are a point of focus. Two key Lean benefits for a process manufacturer are resource balancing and material management.

The goal of a Lean Manufacturing line in a process intensive environment is to achieve the following performance objectives:

- Small batch sizes, ideally linked to customer demand
- Shortest possible changeover (min.) from one product to another
- Lower capital investment
- Easier maintenance and adjustment

The direct labor requirements may actually be higher, and output per line lower, in a Lean manufacturing line than a more traditional automated line. From a flexibility, up-time, reliability and overall operating cost viewpoint, these Lean
cell configurations become a necessity if the company wants to produce a high mix of products, achieve quick response, and reduce WIP inventory.

Material Kanban techniques can be used within a process intensive environment to manage and control the transfer of semi-finished product from a supplying process to a consuming process in a factory. Kanban replenishment techniques can also be used for controlling supplied materials consumed at the required processes. Another common application for Kanban is as a tool to signal the replenishment of finished goods inventory shipped to customers. Finished Goods Kanban is a simple and easy-to-implement first step that can achieve dramatic finished goods inventory reductions in a short period of time.

The conversion of a discrete or process-oriented factory from traditional, batch manufacturing methods to Lean Manufacturing is a production manager’s (and consultant’s) dream, because the benefits are so large. A reduction in WIP inventory of 90% is not unusual, and large improvements in all of the key business metrics are expected.

The toolkit of Lean Manufacturing methods and techniques is extensive and thorough, and the right tools need to be selected for the right applications. Process industries focus on the reduction of variability and changeover times as a large opportunity. Discrete manufacturing takes on the physical linking and balancing of work, and organization of the material delivery system, as their initial focus. Administrative and office processes reduce departmental barriers and increase employee cross-training to get the maximum benefits. Whatever the application, the fundamentals of Lean Manufacturing apply.

Lessons Learned

Lean Manufacturing has its roots in the early 1900’s with the Scientific Management movement. It later matured in Japan, and was introduced to the U.S. in the 1970’s and 1980’s.

By the 1990’s many companies had to convert to Lean methods in order to survive. It is increasingly difficult to be globally competitive using batch and MRP methods. More than a decade later, there is still much work to be done.

No matter how many times they have flown an aircraft, airline pilots use their pre-flight checklists instead of their memories. If fact, they are required to do so.

To flow work is to link and balance all of the work steps required to make a product as closely as possible, eliminate queue time and delays, and to mistake-proof the work steps.
A host of benefits are achieved by flowing work: fast response time, inventory reduction, productivity gains, quality improvements, and reduction in floor space.

Any industry can benefit from Lean Manufacturing methods and many industries have already converted en-masse.

Both process and discrete manufacturing are candidates for improvement with Lean Manufacturing methods.

The Lean Roadmap is a valid methodology far beyond the factory. The authors have successfully applied it to hospitals, banks, and many other non-manufacturing settings.
Chapter 3 Assessment & Preparation

- BUSINESS 101
- LEAN PREPARATION
- THE PROCESS MATURITY MODEL
- THE VALUE STREAM MATURITY MODEL
- THE LEAN ASSESSMENT

The starting point for your journey is to prepare properly for the trip. Leaving home without the right equipment, the right plan or the right destination is certainly a recipe for adventure, but most businesses prefer to take a journey with less excitement and more predictability. This chapter covers some of the preparation steps and business disciplines that you need as foundation principles and practices. Without a strong foundation, the Lean tools and methods that we will be introducing in subsequent chapters may cause more problems instead of less. Some of the issues we’ll be examining fall under the category of “Business 101”, i.e. the basics that are important for any company, Lean or not. Other issues involve the role of management and leadership, without which nothing will happen and nothing will be sustained. Finally, we’ll be looking at some Lean methods that you’ll want to tackle first, including housekeeping, use of business systems and the concept of process and value stream maturity.

Business 101

College introductory courses in many subjects are numbered 101, the first course, and in casual talk we use it to refer to the basics of a subject. In this chapter, we will assess some of the fundamental disciplines that you need to have firmly in place before getting serious about creating a Line Design. These topics are not exclusive to Lean, but necessary for any business, whether they use traditional
schedule-and-push production methods, Lean Manufacturing and Six Sigma, or Intergalactic Manufacturing.

*Inventory Accuracy.* When MRP manufacturing systems were first introduced in the 1970's, the initial training placed a heavy emphasis on achieving and sustaining a high level of inventory accuracy. The reason was simple: MRP needs this information to create an accurate material procurement plan, and if the computer doesn’t know what you have, it’s going to have trouble correctly recommending what to procure. This requirement for high inventory accuracy has not diminished, but in some companies the emphasis once given to this critical business requirement has declined. The result is waste, in the form of parts shortages, disruptions to the production schedule, excess inventory, manual workarounds and negative financial impacts. If anything, the need for accurate inventory records has grown since the 1970's. As you reduce inventories, you run the risk of running out of material faster if you don’t manage your inventory control process tightly.

The key to good inventory accuracy begins with a robust system, including policies, procedures, computers, training and certification. It does little good to fix inventory errors, if you don’t have a system to catch and prevent errors from occurring; they will simply continue to reappear. Once you have a solid process in place, you need to introduce a way to find and correct errors, and use this feedback to continually improve the inventory system. This discipline is called *cycle counting.* Your inventory accuracy goal is to quickly achieve and maintain a 98% or better computer record to physical accuracy level.

*5S or 7S.* The Lean method of 5S (or 7S if you include safety and security) has become well known in recent years, Originally based on five Japanese words that all began with the letter “S”, the terms have been translated into English as Sort, Set In Order or Straighten, Shine, Standardize or Systematize, and Sustain. 5S is a disciplined and structured approach to achieving a high level of organization and housekeeping in the office or factory floor, with a special emphasis on the last S, Sustain. It is impossible to imagine a world-class company that does not maintain a high level of cleanliness and organization, so 5S is undoubtedly something that you need to know about and practice.

It is not uncommon in Lean literature to hear that a 5S program is the first thing that a company should do to implement Lean. We don’t agree. We’ve seen too many companies get sidetracked by company-wide 5S initiatives, and fail to get to the real meat of Lean: the introduction of flow and pull methods that are the heart of this book. Some firms may proceed down a more-or-less exclusive 5S
path, thinking that’s what it means to “get Lean”. We’re not alone in this belief, as a recent article from the Institute of Industrial Engineers confirms:

5S is often touted as a good place to start implementing Lean. What can be bad about tidying up the workplace? Lean factories do have good housekeeping practices; however starting your Lean journey with a plant-wide 5S initiative is not a good idea for two reasons:

There are more productive Lean things to do than tidy up.

If you start creating shadow boards and marking off workstations before you start improving production flows, you risk annoying workers when you redesign workstations and change layouts.

Another concern with an exclusive focus on 5S, is that it is hard to measure benefits directly. There is no doubt that a significant amount of waste is associated with a lack of organization and housekeeping, but converting this benefit to dollars is often hard.

This does not mean that you don’t need to practice the 5S principles. You may need to do some preliminary 5S work if your workplace is in bad shape. You be the judge. The best time to introduce a full-blown 5S program is during the implementation process itself, combined with actual process changes. The 5S disciplines need to be a part of everything that you do, but not the only thing you do.

Business Systems Audit. We are now in the 21st Century, and a failure to have good automated business systems is clearly a form of waste. Having good systems may fly in the face of Lean philosophy. Isn’t Lean all about cards, the visual factory and manual systems? Of course, if something can be done simply, then by all means choose that method. The complexity of most modern business environments, involving thousands of different part numbers, hundreds or thousands of products and people, and global sourcing and distribution, requires more data-processing horsepower. Before you start on your Lean journey, an assessment of your system capabilities is in order.

As consultants, we prefer to work with new clients who are making an honest effort to use a formal system correctly. This implies that training has taken place, that the importance of discipline in entering and managing electronic information is understood, and that some process-related data is already available. Even in a post-implementation Lean world, when running the Lean Enterprise, you will continue to use computers to manage inventory, store engineering and material information, purchase parts, run your accounting system, provide customer
support and manage customer demand. Weakness in these functional areas is a red flag that needs to be addressed sooner than later.

The one module in a traditional MRP system that you may not be using is Shop Floor Control. Our plan is to replace work center scheduling with visual methods, so that the production planning process can be simplified significantly. We don’t throw out the baby with the bathwater, and most of the modules of a traditional MRP system can be used to manage the Lean Enterprise.

**Key Performance Metrics.** Before launching a Lean initiative it would be an excellent idea, if you don’t have one already, to establish a reporting mechanism for the metrics that you want to track in relationship to the progress of the Lean transformation and company-wide performance. Not having a measurement system is like flying a plane without a control panel. You may get to your destination by looking out the window, but we don’t recommend that “fly by the seat of your pants” approach to business. Remember that you plan to achieve great things with your Lean transformation, and you need to have the evidence to prove it, in the form of performance measurements.

Recently electronic management dashboards have become popular. The advantages of a formal graphical display are several: ease of access via the internet, ease of understanding with both numbers and graphs, the ability to select multiple time periods or drill down for more detail, and the ability to perform dynamic what-if analysis. If your information is stored centrally, you can also monitor the metric owner to ensure that the data is being updated and kept current.

Most Lean organizations, including Toyota, prefer to maintain shop-floor data manually. This may seem antiquated, but by having operators and supervisors maintain their own data, using a pencil and a paper graph, the information is much more immediate, real-time, and actionable.

**Mission and Vision Statement.** Most companies have mission and vision statements that purport to represent the company’s values, beliefs, direction and strategy. More often than not, these statements have not been updated in a while, nor can most of the employees state what is contained in them. Before launching a Lean initiative, it would be a good time to review, revise or rewrite your mission and vision statements, based on the new road you’ll be taking. Make sure the statement is something your management team believes in, and not simply something to check off the to-do list. A typical mission statement might sound something like this:

“The mission of [Your Company Name Here] is to deliver superior quality products and services for our customers and communities through leadership, innovation, and partnerships.”
Does anyone actually feel like they’re participating in leadership, innovation and partnerships when they work at your company? If so, great, but this is the type of mission statement you usually want to avoid. Some of the best mission and vision statements are short and to the point, to the level of a slogan or mantra, and expressed in just a few words. Here are some inspirational examples:

Federal Express: “Peace of mind”
Nike: “Authentic athletic performance”
Target: “Democratize design”
Mary Kay: “Enriching women’s lives”

If all else fails, you can always go on-line to one of several automatic mission statement generators. There, without the help of a consultant or without having to make any effort at all, you can have one automatically generated for you.

Lean Preparation

*Management Leadership Training.* One could make a case that this is one of the most important preparation items of all. Lean is not a “grass-roots” effort that will eventually trickle its way to the top. Without strong leadership and consensus from the top management team, your probability of creating a Lean Enterprise is, let’s face it, zero. A Lean initiative never fails when the CEO is strongly involved, and it never succeeds when the CEO is not.

Even if your leadership team verbally expresses strong support for this direction, it is still not clear if they know exactly what they’re talking about or signing up for. There are a host of misunderstandings that exist, and it is critical that everyone in the group be on the same page. The best way to achieve this is to conduct a private Lean workshop designed for the purpose of creating a consistent vision of the Lean Enterprise, and a consistent focus for the leadership team. The workshop should be held off-site to avoid distractions, and at least three days are needed. There should be a practical outcome to the workshop in the form of a high level Lean Master Plan, covering at least the next year.

W. Edwards Deming published his famous 14 Points in 1982, in order to provide guidance for American management faced with the challenge of overseas competition. His feeling was that American management had lost its way, and needed a new beginning in order to survive. Deming also stressed the importance of on-going education. The new philosophy that he refers to, is now call Lean and Six Sigma, as follows.
1. **Institute leadership.** The aim of supervision is to help people and machines to do a better job. Supervision of management needs an overhaul, as well as supervision of production workers.

2. **Adopt the new philosophy.** We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.

3. **Create constancy of purpose** toward improvement of product and service, with the aim to become competitive, stay in business, and to provide jobs.

4. **Institute a vigorous program of education and self-improvement.**

   How can you be sure that your management team is engaged and on-board with the Lean initiative? It’s difficult to cut through lip-service, but one way is to insist that your leadership team be able to teach basic Lean concepts like 5S, Continuous Improvement and Value Stream Mapping. As you have all experienced, if you’re required to teach something to others, it is imperative to understand it yourself. If Lean concepts are properly and correctly understood, it is easy to be enthusiastic about them and become fully committed to their introduction and implementation. We are not suggesting that your top management become full-time trainers, but that they are able to teach, and are occasionally asked to do so.

   **Implementation Leader Training.** In addition to your management team, you need to train the people actually doing the work. Don’t take it personally, managers, but the people closest to the action (the gemba in Leanspeak) will be the ones leading your transformation projects, and the ones you’ll be relying on to generate most of the improvement ideas. These are the people that need to know the Lean details: designing pull system, material management, running employee involvement systems, implementing and sustaining standard work, creating the visual factory, and so on. This knowledge comes through **doing,** but formal classroom training is also important. A general three-day introduction to Lean is recommended, in addition to any specialized training that might be needed. The comments made above regarding the need for teaching ability also apply to your implementation leaders.

   **Workforce Training.** Beyond the management team and the Lean Leadership group, it is necessary to extend Lean knowledge to the entire workforce. What separates the men from the boys in Lean maturity is the **level of engagement** of the entire workforce. Everyone in the company is expected to understand basic Lean concepts like waste, flow and pull, and be able to apply key Lean tools like
5S, problem-solving and standard work. One part of everyone’s job in the Lean Enterprise is Continuous Improvement. It is said that the daily work at Toyota is not only to make cars, but to make cars better. In order to improve fast enough to compete in today’s brutally competitive world, you need help from everyone in the company.

The Lean Roadmap and Project Management. The Lean leadership team will be dealing with a host of on-going projects, improvement suggestions and team activities that will require management. We are providing a structure, The Lean Roadmap, to organize this effort. Each roadmap element needs to be tracked and people need to be held accountable. We recommend that you use a project management tool, and that you make sure the plan is kept up to date. Key milestones from your implementation plan can be integrated into your management dashboard, for additional visibility. The biggest challenge of project management is not the creation of the plan (that’s the fun part), but keeping the plan current and using the plan as a management tool.

The Process Maturity Model

Although the Value Stream Map that you’ll be using in the next chapter will give you a good initial picture of your process flow, Value Stream Maps are missing an additional important data element: an assessment of Process Maturity. Your level of process maturity can be measured easily against a set of criteria defined in the Process Maturity Model, depicted in Figure 3.1, developed by Michael G. Beason and used by the Supplier Excellence Alliance (SEA).

Level 1: The process has been identified, defined, and has an owner. At this stage of maturity, you have given your process a name and assigned a responsible person or owner. The sustainability and success of the process is at risk, and highly dependent on individual management. Training is typically done through the “buddy system”.

Level 2: The process has been documented to the Work Instruction level. At this level, you have created detailed work instructions and are on the road to standardization. You have not yet completely deployed this standardized process to the workforce, and the actual work may still be performed in a variety of ways, depending on the preferences of the individual worker.

Level 3: The process has certified trainers and is standardized. Level 3 is considered the minimum acceptable level. You have a formal training
process in place, with certified trainers. Workers are trained and certified to follow the standard work definition, and an audit process is in place to ensure that this discipline is maintained. A certified worker can perform the work in accordance with the standard work definition, can perform inspection of the work quality, and can meet the time standard established for that process.

**Level 4**: The process is under process control, is analyzed and is improved using data. At Level 4 you gather process-related data, review the data on a regular basis, and take actions to improve process performance. This may take the form of SPC control charts, or through performance metrics. The ability to continually improve the process implies a high level of engagement of the certified workforce in process improvement.

**Level 5**: The process shows continuous positive trends. To qualify for Level 5 of the Process Maturity Model, you need to show a trend of continuous improvement for at least 24 consecutive months. Industry performance metrics, if available, show that your performance meets or exceeds the best in class.

The importance of assessing the level of process maturity is clear and critical: if a process that you are working on is not at a sufficiently high level of maturity, Level 3 or higher, then process changes will not be sustainable. Changes and improvements that you attempt to implement will have a strong tendency to fall by the wayside.

A Lean initiative normally involves several, and usually many, different processes. Realizing that your process or target area is not at a sufficient level of maturity doesn’t mean that you are prevented from advancing on your Lean journey. It does mean that there is some preliminary work that needs to be
completed before you can continue with confidence. Most companies start the Lean journey at a low level of maturity and the Maturity Model helps them focus their attention on process maturity issues as they move forward.

An important use of the Process Maturity Model takes place early. Each defined process on a Value Stream Map is accompanied by a Data Box, which documents the key characteristics of the process, including cycle time, changeover time, and the number of operators and shifts. You should add to the data box an assessment of process maturity, based on the model presented above. You may even choose to color code the process box to identify processes that are at a maturity level less than three, as a target for special attention.

The Value Stream Maturity Model

What if, for the sake of discussion, all of the processes on a Value Stream Map are at a high level of maturity, according to the Process Maturity Model? Does this mean that the Value Stream itself is at a high level of maturity as well? The answer is no. Mature individual processes are a necessary but not sufficient element in a mature Value Stream. There are several additional characteristics that you look for when assessing the maturity of an entire Value Stream, that are not seen at the level of the individual processes:

*Linked Processes.* Most of the queue time (sometimes over 95%) in a Value Stream occurs between processes, in hand-offs from one person to another, or one department to another. You don’t have this visibility if you only look within the process.

*Existence of Flow and Pull.* Flow and pull go hand-in-hand in a Lean environment, so it is logical to look for formal flow and pull methods. Without formal pull systems, inventory will invariably accumulate in the Value Stream.

*Engagement.* By this, we mean a high level of involvement by the entire workforce. Simply improving is not sufficient in a Lean Value Stream. Without the active involvement of everyone in the task of process improvement, it will be difficult to improve fast enough in today’s global economy.

The Value Stream Maturity Model is used to assess the maturity of a value stream, in the interest of creating or modifying a process improvement plan. A Value Stream that is at Level 0 or Level 1 represents a great opportunity. After all, if you’ve survived this long with a low-maturity Value Stream, imagine what you can do when you cut cycle-time by 90%! The following is a description of each
maturity level in the Value Stream Maturity Model, also shown in Figure 3.2.

**Level 1: Identify the Value Stream.** The first logical step in improving a value stream is to identify and document it. This maturity level involves naming a value stream, assigning a value stream owner to it, and creating both current and future state value stream maps. You also want to establish performance metrics for the value stream: cycle time, productivity, and quality.

**Level 2: Flow and Pull.** The biggest opportunity when moving from a traditional work environment to a Lean environment is the introduction of flow and pull methods. Queue time in traditional environments can represent 90% of the total response time. Experience has shown that cycle time reduction is related to a long list of benefits, including improved productivity, better quality, less floor space, improved flexibility, and higher on-time delivery. Much of this book is dedicated to the how-to of flow and pull.

**Level 3: Standard Work.** Once you have harvested the low-hanging fruit of flow and pull, you must continue with the task of training and certifying the workforce in Standard Work. You need to involve the entire workforce in defining the one best way to do work, and to train employees to do the work that way. Remember that standard work does not limit creativity or improvement, but it does determine the way the work should be done for the present time.

**Level 4: Engagement.** The stage of engagement is what separates the men from the boys, when we are assessing Value Stream maturity. Until you are able to involve the entire workforce in the creative work of Continuous Improvement, your Lean efforts will continue to be vulnerable to outside competitors simply copying what you have done. Once you are generating hundreds and thousands of small improvement suggestions a year, it will be very difficult for the competition to keep up.

**Level 5: Sustained Performance.** Until you are able to incorporate flow, pull, standard work and employee engagement into your company culture, things will inevitably backslide. You can claim that you are at Level 5 on the Value Stream Maturity Model if you are able to show that you have maintained improvement for a period of at least 24 months.
The Lean Assessment

It is important to have a formal method or structure to measure your readiness for the Lean journey, as well as measure your progress along the way. You’ll want to take an assessment periodically, to compare results and measure your rate of progress. There are a number of comprehensive assessments available, including an assessment developed by the Malcolm Baldrige association, and a Lean assessment created by the Shingo Prize association. Both of these assessments can be found on the web.

How long should it take to get through the assessment for your site? This depends, of course, on where you’re starting from. It’s likely that even companies that are fairly mature in their Lean journey need to do some preparation work, especially in the area of training and planning. Others may need to begin their journey with inventory management or basic housekeeping. Just don’t take too long; your competitors aren’t waiting around for you. The big jump in benefits and performance will come when you actually design and implement your new flow line, so you still have many miles ahead!

Lessons Learned

Assess where you are performance-wise before you start making changes based on your knowledge of Lean tools.

Get ready for the journey. Move fast but do not rush. Make sure that you know where you are headed.

Get management on board. A bottom-up approach will yield limited results that are at risk of being lost.

Train everybody. But remember that not everybody needs the same training.
Be organized and use project management thinking and tools.

Know your limits. Get help when you do not know something.

Apply the Process Maturity Model and the Value Stream Maturity models. Add them to the data boxes used in the Value Stream Mapping methodology.

Remember that low maturity processes and Value Streams will not be sustainable. Focus your improvement efforts on getting them to a high level of maturity first.
So far we have discussed some of the characteristics and benefits of Lean Manufacturing, and you understand the assessment and preparation steps enabling you to advance on your Lean journey. Now you need to apply a set of tools and a methodology to help you understand and document the current environment in detail, to create a Line Design. The right way to eat an elephant is one piece at a time. But what piece should you eat first? The tools that we describe in this chapter have been around for a long time, have been widely used by Industrial Engineers, and adapted and enhanced to fit your current needs.

When a company improves its performance, through the application of Lean techniques to its manufacturing or administrative processes, it does so with the understanding that it must adopt Lean as a new way of life. At the highest management levels of the company, there has to be a process-oriented vision of high financial and market performance, through the creation and delivery of value to its customers. In this high-level vision, all the processes in every value stream are linked and balanced to allow work to take place without bottlenecks, delays, queues and other forms of waste. To achieve this, however, you need to follow a step-by-step method, based on a logical and proven analysis process.

The first step in the process of defining a target implementation area will be to
consult a map and survey the road you want to travel. In this case, you won’t be able to purchase a travel guide; you’ll need to create the map yourself. The use of an accurate map to guide your trip will keep you from getting lost, will help in the creation of a valid itinerary, and help set priorities for your journey. In the Lean world this document is called a Value Stream Map.

**Value Stream Mapping**

Although flow-charting is a time-honored method for understanding work flow, and for analyzing and improving business processes, the technique of Value Stream Mapping (VSM) was developed more recently during the 1990’s, specific to the tools and methods of Lean Manufacturing. The VSM technique became widely known after the publication in 1998 of *Learning To See* by John Rother and Mike Shook. Since then the method has been adapted worldwide, as an accepted starting point for a Lean transformation. The Value Stream Map represents a high-level view of all of the main processes required to build a product, from suppliers to planning, to production, to your end-customers. What is unique about Value Stream Mapping is the use of Lean-specific symbols. All of the principal Lean methods are represented using specific symbols or icons. Once the symbols are understood, a great deal of information about your current and future state environments can be communicated clearly and easily. Another characteristic of Value Stream Mapping is a focus on cycle-time, and a time line is created at the bottom of the map to measure the overall response time of the value stream.

A Value Stream Map is created based on an understanding of your products and logical product groupings, and a separate map needs to be created for each logical grouping of products, or your *Preliminary Product Families*. We stress the word preliminary because you do not yet have enough data to finalize your product family definitions. You need a starting point, however, based on your existing product knowledge and experience, and you will refine your product family definition as you go forward. Your first goal is to create a Value Stream Map, using specific Lean symbols, of the processes required to build your main products.

We recommend that you do a physical walk-through of the various process steps when creating your Value Stream Maps, starting from the end. The reason you start at the end is simple: a product will have only one completion point, but could have many starting points. The Mississippi River, for example, ends in the Gulf of Mexico, but it has many tributaries and potential head waters. So start at the Gulf of Mexico and work your way upstream. Of course, if the process flow is well understood or very linear, whether you start at the beginning or end makes little difference.
You first create a Value Stream Map that shows your current condition, warts and all, called the *Current State Value Stream Map*, as depicted in Figure 4-1. Then you identify and document opportunities to improve flow and eliminate waste, in the form of *Kaizen Burst* symbols. If Lean is new to you, you might need some outside help in identifying these opportunities. You then create a *Future State Value Stream Map*, incorporating these improvements into a new VSM. Finally, write an implementation plan that takes you to this future state through a controlled series of improvement activities, projects or *Kaizen Events*. Implementing in smaller, strategically selected areas will promote success for a number of reasons:

- You achieve results and benefits quickly.
- You get an opportunity to learn from experience, and improve upon the implementation methodology for the next event.
- If you use consulting support, you have a chance to see the experts in action without waiting an extended period of time.
- You also have the opportunity to learn from their experience, which will enable you to become self-sufficient sooner.
- You can adapt the implementation methodology to your company’s culture and test it again.
- You can overcome nay-sayers more easily by pointing to an initial success.

The implementation area that you finally agree on will be decided by its physical location within the company, by the products built in the area, or by the manufacturing or business processes within its boundaries. Financial performance is the usual guide for picking the first implementation or improvement project. It is very common to see that a plant within a corporation is chosen because of the potential financial gains derived from the application of the tools of Lean Manufacturing. We also recommended starting at the process closest to the customer, since this will provide you with a clearer picture of your customer’s demands, as well as an almost immediate impact on customer satisfaction.

The purpose of the *Current State Value Stream Map* is to create a realistic picture of the way things are, from suppliers to customers, using this flowchart as a springboard to the creation of an improvement plan. Mapping the value stream for each product family will help to ensure that you are looking at the big picture, and not simply focusing on processes that you are familiar with, or that you assume are problematic.

The examples provided in this and future chapters are based on a realistic but imaginary factory with families of custom power tool products. We will follow the line design implementation process step-by-step using these products, which will be described in detail in upcoming chapters. The *Current State Value Stream Map*
Customer Demand:
4,100 Units per Month
205 Units Per Day
(Takt Time 123 seconds)

Finished Goods Warehouse

Motor Assembly
Total C/T = 2.63 minutes
Distance Traveled: 150 ft.

Weekly Schedule

Harness Assembly
Total C/T = 0.7 minutes
C/O = 2 hours
Distance Traveled: 33 ft.

Weekly Schedule

Plastic Molding
Total C/T = 3 minutes
C/O = 5 mins.
Distance Traveled: 86 ft.

Weekly Schedule

Electrical Test
Total C/T = 1.3 minutes
C/O = 5 mins.
Distance Traveled: 86 ft.

Weekly Schedule

Final Assembly
Total C/T = 7.88 minutes
Distance Traveled: 234 ft.

Weekly Schedule

Harness Assembly
Total C/T = 0.7 minutes
C/O = 2 hours
Distance Traveled: 33 ft.

Weekly Schedule

Motor Assembly
Total C/T = 2.63 minutes
Distance Traveled: 150 ft.

Weekly Schedule

Harness Assembly
Total C/T = 0.7 minutes
C/O = 2 hours
Distance Traveled: 33 ft.

Weekly Schedule

Final Assembly
Total C/T = 7.88 minutes
Distance Traveled: 234 ft.

Weekly Schedule

Motor Assembly
Total C/T = 2.63 minutes
Distance Traveled: 150 ft.

Weekly Schedule

Pack
Total C/T = 2.42 minutes
Distance Traveled: 850 ft.

Weekly Schedule

Test
Total C/T = 4.89 minutes
Distance Traveled: 234 ft.

Weekly Schedule

Weekly Schedule

Weekly Schedule

Weekly Schedule

Current State Value Stream Map
Product Family: Electric Drills

Figure 4.1
in Figure 4.1 shows the flow of materials and information for one of our sample product families, electric drills. The current set of required processes, including production planning, suppliers and customers, are represented on this Value Stream Map.

Of great interest to the Lean practitioner is the timeline shown on the bottom of the Value Stream Map. Sometimes referred to as the castle wall, it displays and totals the work content and queue time for each process and inventory step. We are primarily interested in the ratio of total time, including queue, to the work content time. It is not unusual to find that for 95% or more of the elapsed time you are not working on the product, but instead it’s waiting for the next process step. Reduction of queue time represents a huge and relatively easy opportunity to improve customer response time, quality, productivity, WIP, inventory and floor space. One of the primary changes you should expect in your transition to Lean Design, is a radical reduction in total response time, with a corresponding reduction in WIP inventory. Keep in mind that in a traditional work environment, workers are allowed to move or “push” work to the next step, whether or not the next step is able to work on it. The amount of inventory between steps is therefore highly variable and typically high. The inventory shown on the Current State Value Stream Map (assuming that you are currently pushing work) is an estimated average. Don’t worry about whether or not it is “accurate”, as long as it is reasonably representative.

While each company is unique, a traditional manufacturing environment exhibits many common characteristics documented on the Current State Value Stream Map. Traditional office or manufacturing environments tend to:

- “Push” material or paperwork from one work center to another via work orders, scheduled start and due dates, or inter-office mail.
- Experience a high level of queue time and WIP inventory between work center hand-offs.
- Use formal computer systems to generate production schedules that are sent to the various departments and work centers.
- Communicate with outside suppliers via purchase orders with specific due dates and quantities.
Current State Value Stream Map
Product Family: Electric Drills

Customer Demand:
4,100 Units per Month
205 Units Per Day
(Takt Time 123 seconds)

Weekly Schedule
Weekly POs
Monthly Forecast
Finished Goods Warehouse

Weekly Schedule
Weekly Schedule
Weekly Schedule
Weekly Schedule

Supplier
Motor Assembly
Motor Assembly
Plastic Molding
Electrical Test
Harness Assembly
Final Assembly

Weekly Schedule
Weekly Schedule
Weekly Schedule
Weekly Schedule

Weekly Schedule
Weekly Schedule
Weekly Schedule
Weekly Schedule

Lead Time = 40.3 hrs.
Processing Time = 17.8 mins.
Travel = 1734 ft.

Figure 4.2
• Ship finished products to a finished goods warehouse, instead of directly to the end-user.
• Exhibit long response times and low inventory turnover.

While you have not yet gathered all of the information and detail needed to design the new line, you can apply general Lean concepts to your Current State, to identify opportunities for improvement as depicted in Figure 4-2. One of the special symbols you use is the Kaizen Burst, in which you document the improvement opportunity. For example, if a certain process experiences excessive changeover times, you place a Kaizen Burst symbol next to that process with the note “Changeover Reduction”.

In your sample factory, you have identified several Lean opportunities for improvement, and placed them on the Current State Value Stream Map. Your biggest improvement is to implement a flow line, and connect all of our processes with pull signals instead of pushing material with a production schedule. Raw materials can be delivered via Material Kanban methods, and be replenished as they are consumed. The plastic molding process will benefit from changeover reduction. With a greatly reduced response time, you can go from a weekly schedule to a daily production plan, which only needs to be communicated to the Final Assembly process.

As you add Kaizen Bursts to your Current State Value Stream Map, you create a vision for the future, as shown in the Future State Value Stream Map in Figure 4-3. You create the Future State VSM by incorporating the process improvements identified on the Current State VSM, and represent these prospective improvements in an updated map. Your Value Stream Maps are the basis for a formal implementation plan, including planned projects or Kaizen events, dates, and team leaders.
Future State Value Stream Map
Product Family: Electric Drills

Customer Demand:
4,100 Units per Month
205 Units Per Day
(Takt Time 123 seconds)

End Customer

Weekly Requirements

Production Control/MRP

Daily Production Schedule

Harness Assembly and Test Cell

Motor and Final Assembly

Test

Pack

Supplier

PLASTIC PARTS SUPERMARKET

PLASTIC PARTS

FIFO

Motor and Final Assembly

FIFO

Test

FIFO

Pack

PLASTIC PARTS SUPERMARKET

FIFO

Motor and Final Assembly

FIFO

Test

FIFO

Pack

Lead Time = 258 mins.
Processing Time = 17.8 mins.
travel = 245 ft.

Future State Value Stream Map
Product Family: Electric Drills

Customer Demand:
4,100 Units per Month
205 Units Per Day
(Takt Time 123 seconds)

End Customer

Weekly Requirements

Production Control/MRP

Daily Production Schedule

Harness Assembly and Test Cell

Motor and Final Assembly

Test

Pack

PLASTIC PARTS SUPERMARKET

FIFO

Motor and Final Assembly

FIFO

Test

FIFO

Pack

PLASTIC PARTS SUPERMARKET

FIFO

Motor and Final Assembly

FIFO

Test

FIFO

Pack

Lead Time = 258 mins.
Processing Time = 17.8 mins.
travel = 245 ft.

Figure 4.3
The Future State VSM shows the substantial changes that will be made. Overall lead time dropped from 40.3 hours to 258 minutes, and the distance traveled from 1,734 feet to 245 feet. You are now able to respond directly to customer orders, using a make-to-order production strategy instead of make-to-stock. Suppliers are more closely linked via pull signals, so you can expect a reduction in both WIP and raw material inventories. The scheduling system has been greatly simplified, with only one scheduling point required at the Final Assembly process. This is your vision, which hasn’t been implemented yet. As you progress through the chapters of this book, we’ll describe in detail the proven path for making these improvements a reality.

Since you need to create a Value Stream Map for every major grouping of products, or product families, it would be normal and expected to find that you have quite a few different Value Stream Maps when you’re done. What you need is a logical way to compare the various opportunities and benefits, apply a weighting system, and create a ranking for each family.

VSM Cautions

While the Value Stream Mapping method has taken root, or has even become gospel in Lean circles today, you need to be careful not to go overboard. A article in the Journal of Industrial Engineering had this to say:

*You should design a system to perform well, not spend your time analyzing the poor design of the current system. A product flowchart of part of the plant may be useful to demonstrate how poor the layout is to upper management. Spend time designing new layouts to improve product flow, reducing setups, removing process variation, and developing standard work methods.*

The lesson is that you should not make a career out of creating and recreating flow charts, but rather get on with the work of implementing improvements. You also need to be aware of some inherent weakness in the Value Stream Mapping method:
1. Including suppliers on the upper left side of the VSM does little other than identify that you have suppliers. Even the authors of *Learning To See* added this comment: “Just draw the flow for one or two main raw materials”. But let’s be honest: this piece of information is essentially useless. You need to analyze your material supply chain using other Lean tools, like the *Plan For Every Part* method.

2. The customer box on the upper right side of the map is likewise incomplete. You probably have many different customers for the same product family, with different requirements.

3. As mentioned above, in a push environment, WIP inventory or queue time is highly variable. You need to know it’s there, but the numbers used in the VSM are only estimates.

4. In a multi-product line or cell you are producing a variety of different products within the same product family. The yield, scrap and work content time can vary by product. A single process box doesn’t capture the detail needed to complete a thorough analysis. We will be addressing this in later chapters.

5. The format of the VSM does not lend itself easily to more complex flows, like multiple feeder lines and optional processes. For that reason, the examples shown in the VSM literature are always simplified compared to real-world examples. You can overcome this with the Process Flow Diagrams technique shown in a later chapter.

6. You don’t have all of the information at this stage of your journey to complete an accurate understanding of a product family. You need to understand the process flow for every *individual member* of the family, particularly if you have optional processes. You have significantly more data collection to do.

The bottom line is, we regard Value Stream Mapping as an important tool. The design of a true multi-product flow line will require that you capture significantly more information, presented in the upcoming chapters.

You should not limit your thinking to the factory alone. If you think of the output of an administrative value stream as a “product”, you can map the processes and create both a Current and a Future State Value Stream Map just as easily. To mail a completed invoice, you identify various suppliers, processes that could involve multiple departments, and an end-customer who receives the invoice. You also expect to see the same sorts of opportunities for improvement:
reduction of queue times, reducing errors, lowering the backlog and avoiding the accumulation of paper.

Selecting a Target Area

To help in the selection, and in prioritizing a worthwhile target area for your Lean efforts, you need to create a checklist of attributes, and create a weighted scoring system. You need to see a high number of yes answers to the following questions, in order to make sure that you are selecting a suitable implementation project. If less than 50% of the questions can be answered positively, look for other opportunities. The factors you will be scoring include the following:

**Significant quantifiable benefits.** The kinds of benefits normally associated with a Lean project include reduced cycle time, reduced inventory, improved productivity, reduced floor space, reduced scrap and rework, and improved housekeeping. It is always preferable to express these anticipated benefits in the common denominator of dollars, although this is sometimes difficult. If the benefits of a flow project cannot be quantified, or if the benefits are modest, this is a red flag to warn you that your time would be better spent elsewhere.

**Medium to high process maturity.** The Process Maturity Model was discussed previously, and should be applied to your proposed target area. While a low maturity does not automatically rule out the area as a candidate, it does mean that some preparatory work needs to be completed in the areas of process documentation, training and certification, and process control. These activities can take place as a part of your Lean initiative, with the understanding that additional time will be needed. More specifically, lower process maturity means some extra work during Phase II, the data gathering phase of The Lean Roadmap.

**High Process Stability.** While the process maturity concept is focused on standard work, training, certification and process management, process stability refers to yield or repeatability. In order to implement flow in an area, it is necessary to have acceptable levels of repeatability, so that scrap and rework are not a significant challenge. You do not need to be at the level of Six Sigma quality, 3.4 defects per million opportunities, in order to proceed with a Lean initiative, but if your processes are unstable you should work to stabilize them first.

**Low Risk.** While the word guaranteed may sound a bit strong, you want to select a target area where there is little doubt that the goals of the implementation can be met. This is critically important for your first implementation project. It is important that the Lean initiative succeed, in order to build confidence and enthusiasm for future efforts. Management is unlikely to fund future Lean projects
if there is a past history of failure. Why would a Lean project fail to be successful? There are a variety of reasons, the foremost being weaknesses in leadership and culture.

**High visual impact.** People need to see that a change has taken place. After a Lean project, if the area looks the same as before, the logical conclusion of a casual observer would be that nothing has actually changed. After a Lean project, the desired response from your co-workers, suppliers and customers should be “wow”. This requires a very high level of organization and housekeeping (5S) has been achieved, in addition to the structural process improvements.

**A complete Value Stream.** Your target area should be able to produce a completed product, and not just focus on a sub-process or processes. If you cannot complete a product as a part of your Lean initiative, it will be difficult to see and appreciate the improvements that have been made. The ability to complete a product is a good rationale for starting your implementation from the end of the value stream, to have a direct impact on the completed product and your customer.

**Can be replicated.** When it comes to process improvements, our motto is “Steal Shamelessly”. Why try to reinvent the wheel if a perfectly good improvement has already been implemented elsewhere, in another department or company? This is not literally stealing, it is merely being smart and using ideas that are freely available to you. A successful Lean project can be helpful to other areas in your company, by showing them the way and shortening implementation time.

**Makes a significant impact to a bottleneck or restriction.** The Theory of Constraints tells us that your flow rate through a value stream will never be any faster than your slowest process. By improving a critical process constraint, we can improve throughput, reduce WIP inventory among other benefits.

**Has a significant market impact.** The customer pays all of the bills, so if improvements in the target area have a significant positive impact on your customer, it makes sense to select that area. Improvements that directly benefit the customer include improvements in response time, quality and flexibility.

**Is an operational problem, not management or policy.** You should focus your improvement efforts on a tangible operational problem, especially as you start your Lean journey. Policy and management issues are also included under the Lean umbrella, but in the category of tools called Hoshin Kanri. This large and important body of knowledge is not addressed in this book.

**Has medium to high volume.** Select an area with significant volume. This ensures that you have work available in the target area, and the benefits achieved have a greater impact on the bottom line.
**Is the worst area of the plant.** Remember that you want your Lean efforts to be highly successful, so focus on the biggest problem product or area. A success in the worst area of the plant will communicate a strong New York style message: “If you can make it there, you’ll make it anywhere”. Be assured that you will succeed, otherwise the message will be just the opposite.

**Is a Value Stream that wanders all over the plant.** Linking work together in a new layout will result in increased productivity and the elimination of non-value-added walking and material movement. You may be very surprised at the benefits of doing a re-layout based on Lean principles.

**Is buried in WIP.** Work In Process inventory is tied not only to waste of working capital and poor housekeeping, but it’s also the main contributor to long lead-times and low quality. Focusing on an area with lots of WIP, and reducing it, will send a powerful visual message when the area looks completely different afterwards. WIP exists in the office as well, in piles of unfinished paperwork.

**Is an area where operators are cross-trained.** Cross-training in a Lean environment is not only recommended, it is required. Selecting an area where the operators are already cross-trained will reduce the amount of preparation needed, and accelerate the implementation process greatly.

**Has relatively good O.E.E, which stands for Overall Equipment Effectiveness.** It is a measurement of availability, quality and performance of production machinery, expressed as a percentage. Low O.E.E. is a significant impediment to good flow, and should be considered a process stability issue.

## Creating A Lean Master Plan

Once you have selected your Target Area, based on the criteria described above and the potential benefits to be achieved, you are ready to create an action plan or a Lean Master Plan. In this plan, you define the activities or tasks that you will be completing, who will be responsible for this work, and the time frame in which it will occur.

The easiest way to create a Master Plan document is to use a project management software tool. Assigning dates, resources and many other parameters, and giving you a tool for tracking these activities, is what this software does best. Value will be created when you actually implement the process improvements you’ve been planning, and not before. Your Master Plan should be concise and to the point, and you should get it done quickly and move forward.
We are now ready to explore in detail the proven methods for implementing a Lean process. We’ll use our fictitious (although realistic) custom tool factory to illustrate each implementation step in the upcoming chapters. The journey has just begun!

**Lessons Learned**

Use Value Stream Mapping as a tool to get you started, but do not make a career out of flow charting. Get out and get improvements going!

Develop logical and quantifiable criteria for selecting the target area.

Sometimes numbers do not tell the whole story. You need to maintain a balance between hard dollar figures and intangibles, such as the learning experience resulting from the target area selection and the impact on the enthusiasm of the rest of the organization, the “me too” effect.

Make sure that you have a clear table of benefits with metrics that have been reviewed and agreed upon by the management team.
In Chapter 4 we discussed the need in your Lean journey to consult a map and survey the land that you are considering traveling through. The use of accurate maps to guide your trip will help keep you from getting lost, help in the creation of an valid itinerary, and will set priorities for the time that you have available. In the Lean Manufacturing world, this tool is called a Value Stream Map. Once you arrive at your destination you also need some guidance, this time more detailed and specific, like the map of a city. These types of maps are known as Process Flow Diagrams. The creation and use of the second kind of map, the Process Flow Diagram, is the subject of this chapter.

What Is A Process?

The term “process” is another way of saying “work”. Our definition of the term is:

*A process is a collection of sequential steps of like work performed by people, machines or a combination of both, at a constant volume.*

When you walk through a physical area to create your Process Flow Diagrams or Value Stream Maps, you organize work into logical groupings. The work within a group will be the same type (assembly, testing, analysis, design, inspection) and occur within the same physical area. Work that is moved from one physical area
to another, or one building to another, will incur some move time and queue time. On a Value Stream Map, move and queue time would look like this:

![Value Stream Map Diagram](image)

**Figure 5.1**

In this example we are documenting work that requires a 400 foot move. Because the work is being handed off to another department, we also incur queue or waiting time, estimated here to be four hours.

The second part of our definition, *at a constant volume*, requires some clarification. When designing a production line or an office cell, it is important to have a capacity goal or target that you are designing for, as discussed in the upcoming chapter *Demand and Takt Time*. The demand for each process takes into account scrap and rework, quantity consumed, differing work times and optionality. The rule is that for design purposes, a process *can only have one demand or volume*, the sum of a mix of products. If the volume changes within a process, this will define where one process ends and another one begins.

Being able to define a process correctly is absolutely necessary, to achieve the right level of detail when you create your Value Stream Maps or Process Flow Diagrams. Think of the analogy of flying in a plane and surveying the land beneath. If you fly too low, you’ll be too close, or see too much detail. Your Process Flow Diagram or Value Stream Map would be very complex and unwieldy. If you fly too high, you won’t see enough detail. In this case your Process Flow Diagram could be technically correct, but practically useless and not detailed enough. The definition of a process, as discussed above, achieves the right level of detail.

**The Preliminary Product List**

The first step in gathering the information to create a line design is to identify the prospective products to be built on the line. Table 5.1 displays the list of products that will be used for our power tools line design. Your objective is to design a mixed model line, capable of building *all* of these products. It is not a given at this stage in your journey that all of the products are actually a good fit together. You
need to gather some basic information before making decisions as to what shape the line will have, and which products can be combined into a single line.

Your list of products does not need to be exhaustive, and not every single product that will be built on the line needs to be included in the analysis. You will always approach the design by focusing on products that represent the highest production volume. Companies often have a long list of products that could be built, but the active product list is typically much smaller. Designing for the high volume products does not mean the rest of the product offerings are ignored. The line will be designed to manufacture all the products within the target area.

It is also very important to ensure that all the products that have unique processes or manufacturing resources associated with them be included in the product list, regardless of their volume. It is a common practice to begin the transition to Lean Manufacturing by conducting a pilot project for a section of the factory. The product list could be one of the factors in determining the boundaries of the design scope.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR12</td>
<td>Drill</td>
</tr>
<tr>
<td>DR54</td>
<td>Drill</td>
</tr>
<tr>
<td>DR11</td>
<td>Drill</td>
</tr>
<tr>
<td>SD04</td>
<td>Sander</td>
</tr>
<tr>
<td>CS87</td>
<td>Circular Saw</td>
</tr>
<tr>
<td>OS31</td>
<td>Orbital Sander</td>
</tr>
<tr>
<td>OS01</td>
<td>Orbital Sander</td>
</tr>
<tr>
<td>CH96</td>
<td>Chain Saw</td>
</tr>
<tr>
<td>CH09</td>
<td>Chain Saw</td>
</tr>
</tbody>
</table>

Table 5.1

In office process designs, the determination of the product list is one of the more challenging aspects of the project. What is the product of office work? Look for discrete units of output. These units of output could be a customer order ready to be transferred to manufacturing, a request for a product return, or a processed credit application. In a hospital Lean process design, a common product definition is case types.

The Process Flow Diagram

Once the products have been identified, the next step is to understand how these products are built. A product is manufactured by transforming materials through
work. The work applied to a product requires different resources: people, machines, or a combination of both. Production resources are grouped into processes, and you design your line process by process. The flow of manufacturing processes to build a specific product is documented in its Process Flow Diagram (PFD). Each PFD shows how the materials flow from process to process to build one unit. The manufacturing processes in the sample factory used in this book include Final Assembly, Test, Pack, and Injection Molding. In your factory you will go to the factory floor, and draw a PFD for every product on your list. Document all of the manufacturing processes, and how they are related. A PFD for some of the products in our power tools factory is shown in Figure 5.2.

![Process Flow Diagram](image)

**Figure 5.2**

As you can see, the PFD is quite a bit simpler than a Value Stream Map. All you need is a process name and an arrow. This simplified flow chart format can document complex relationships and a large number of different processes more easily than the VSM format. It gives you the flexibility to capture a variety of paths, including the occasional rework loop that goes backwards in the flow.

It is common to find that a PFD applies to more than one product. A PFD must document all of the paths the product follows as it is manufactured. Sometimes a product does not advance forward as desired, so you need to document any loop-backs of rework that may exist. The Process Flow Diagram for a product also shows the relationship of work and time, with the processes drawn in the order in which they occur in the factory floor. One PFD at a time, you are gathering one of the most critical pieces of information for the flow implementation. The PFD will allow you to understand the number of units flowing through any individual process, the process throughput.
Make sure that the PFDs are an accurate reflection of the factory. Routings, Bills of Materials, and subassembly definitions may serve as supporting documentation, but relying only on legacy data will lead you to an inadequate, if not flat-out wrong, line design. When working on your next mixed-model line design, wear comfortable shoes, and be prepared to walk the factory floor.

Having completed the documentation of all the process relationships in the form of Process Flow Diagrams, you now have a stack of paper that needs to be analyzed. To make sense out of the PFDs, you must organize them in a form that allows you to see patterns of flow paths followed by all the products. The tool to be used for organizing the process relationship data is the Process Flow Matrix, discussed in the next chapter.

Figures 5.3, 5.4 and 5.5 are three additional Process Flow Diagrams that were created with a PC-based flow-charting software tool. The advantage to using dedicated software is for both ease-of-use and to maintain our process information in a central repository or shared folder. Once you have documented all of your
PFDs, you should also compile a list of all of the processes required. You will need this later on in your line design journey.

Is Queue Time Included?

One of the useful and often eye-opening features in a Value Stream Map is the documentation of queue points or accumulated inventory, expressed in pieces or days of inventory. This inventory adds greatly to the total response time of the value stream; up to 95% of the elapsed time can be queue time. A question that often arises when you begin to create your Process Flow Diagrams is “What happened to the queues? We know they’re still there!”

Queue points are not included on our Process Flow Diagrams, for a number of reasons. First, you have already documented queue points during your preliminary Value Stream Mapping exercise, so you are already well aware of where material or information accumulates. Second, at this stage you are not documenting a product family or a product line, you are creating PFDs for individual products. At this level of detail, individual queues don’t make sense. Leaving queue points out also simplifies your Process Flow Diagrams considerably, and considering the volume of data you will be dealing with, this is a significant benefit. Finally, and most importantly, you plan to design out these queue points and eliminate them or replace them with Lean tools like In-Process Kanbans (IPKs) or Supermarkets. If they will be eliminated, in any case, why include them?
Using Software Tools

Process Flow Diagrams, as with Value Stream Maps, are first created with a pencil, paper, Sticky Notes and brown butcher paper. Soon thereafter it is advisable to convert your initial hand-made work into a format that can be stored, shared and backed up. Any of the Microsoft Office applications can be used, including Word, Excel and PowerPoint. A flow-charting program like Visio can make the job quicker, and there are a host of other products on the market that can do similar work.

The disadvantage of any of these stand-alone applications is just that: they are stand-alone. A PowerPoint slide of a PFD can be perfectly accurate and correct, but it’s difficult to share or access the data other than viewing it or printing it out.

Process Owners

As you complete your Process Flow Diagrams, you have defined and documented a list of processes. One of the sustainability concepts that we introduce at this point is the Process Owner. The Process Owner is an individual who is assigned the responsibility for the following actions:

1. **Standard Work.** The creation and maintenance of Standard Work Definitions for the process. Standard Work is a topic that will be addressed in detail in a later chapter, but suffice it to say, it is a highly important element of the Lean approach. As stated by Taiichi Ohno, father of the Toyota Production System, without standardization there is no continuous improvement or Kaizen.

2. **Training and Certification.** It is not enough to document a process. You must make sure that the employees working in that process are properly trained to do Standard Work. The verification of this training is what we call certification: confirmation on the part of a trainer that the employees know the work, are able to perform any documented quality checks, and can meet reasonable time standards.

3. **Continuous Improvement.** The Process Owner is responsible for overseeing the Kaizen or continuous improvement efforts that are on-going. Standardizing does not mean stagnating, and one of the most outstanding characteristics of a Lean environment is the rate of improvement. Lean organizations are never satisfied with the status quo, and the Process Owner is the #1 non-conformist.
Formalizing the role of the Process Owner in a documented system will also allow the leadership team in a company to monitor results and ensure sustainability. If training records are linked to Processes and Process Owners electronically, you can easily determine training needs and areas of strength and weakness.

The Mixed Model Process Flow Diagram

Once you have created the Process Flow Diagrams and associated them with every product in the preliminary product family, you are able to create a Mixed Model Process Flow Diagram that includes every defined process and process relationship. The Mixed Model PFD does not represent any individual product, but is the combination of all of the individual PFDs. The Mixed Model PFD is an essential tool when you create a preliminary layout of the process flow. Even low-volume processes need to be included on this drawing, since you will on occasion be required to use them. Figure 5.6 is an example of a Mixed Model PFD.

Figure 5.6
Mixed Model Process Flow Diagram
The Mixed Model PFD is still a work in process at this stage, since you have not finalized your product family yet. That’s a topic for the next chapter. Until you have finalized your product family definition, the Mixed Model PFD is still preliminary.

Value Stream Mapping and PFDs

The VSM method, as you saw in Chapter 3, is to document an overall picture of a value stream that includes all of the essential processes required to build a family of products. This scope includes not only the manufacturing processes, but includes raw material procurement, warehousing, product design, administration and customer service, computer processes, etc. It covers the flow of information as well as materials. It documents the big picture, with a view towards optimizing the entire flow, not just a piece of it. As such, the Value Stream Mapping effort is often a starting point for a company implementing Lean Manufacturing. Is a PFD the same thing as a VSM? From the standpoint that they both pursue the same objective, the answer is yes. However, while VSM is a high level depiction of the relationship of product family processes, the PFD is a tool within a practical line design methodology that will lead toward the physical design of a set of processes, with precise locations defined for all the resources within each process. The scope of a PFD is limited to the direct manufacturing processes in the target area, and does not include other support processes. After all, there is no point in showing information that will not be used in our design. The factory floor is where we start, because if our manufacturing processes are not flowing well, this will have negative repercussions on all of the supporting activities. Most of the added value takes place in manufacturing, although significant components of lead-time can also occur elsewhere. Is Value Stream Mapping important? Absolutely, and it should be done. Where do you start implementing? In manufacturing.

Test Your Understanding: Defining A Process

Let’s create some examples so that this concept is clear. Here’s a chance to test your understanding. You can find the answers immediately below.

1. Two areas of the plant do Final Assembly work, and the products flow sequentially from one area to another. Area 1 works one shift, while Area 2 is works two shifts. How many processes (minimum) are required?

2. The Test process consists of 5 test steps. Approximately 10% of the units need to repeat step 3 (only) due to required adjustments. How
many processes (minimum) are required?

3. Each unit contains a chassis and four wheels. The wheel line is continuous with the chassis line, connected directly as a feeder line. How many processes (minimum) are required?

4. Invoice processing can be done as a continuous series of work steps. The invoice must be transferred to Engineering (in another building) for final analysis prior to mailing. How many processes (minimum) are required?

5. A line with six processes experiences scrap at the end of the line. The scrapped unit is thrown away and needs to be replaced. How many processes (minimum) are required?

Answers

1. Two. Whenever there are time differences, volume going through the process will be different. Although the work is the same, two separate processes need to be defined.

2. Three. Steps 1 and 2 would be one test process, Step 3 has a 10% higher volume, so a different process would be required. Steps 4 and 5 have the same volume as 1 and 2, but the steps are not sequential, so a third process name would be needed.

3. Two. The chassis and wheel processes have different volumes, where the number of wheels to be produced is 400% of the volume of chassis.

4. Two. Both the type of work and the location are different.

5. Six. The overall volume of the line needs to accommodate the scrapped units, but the volume difference affects all six processes equally.

Lessons Learned

You began your Lean process design with a preliminary product list, and by assembling a list of processes, so you can develop a Process Flow Diagram for each product.

The Process Flow Diagram documents the processes required to build each product, and how those processes are sequenced.

The goal is to design a flow line that can build multiple products in the minimum
elapsed time, with the highest quality, and the lowest cost. The Process Flow Diagram will be used to guide the design of the optimal line layout.

Value Stream Mapping, and Process Flow Diagrams are similar methods. Value Stream Mapping is used to create a big picture view of the target area, while the PFD is a practical tool used for Mixed Model Line Design.

Before you create a physical line layout, you need to have a Process Flow Diagram that shows all of the required processes. We call this the Mixed-Model Process Flow Diagram.
A product family is a group of products that require similar processing steps, similar processing times, and share common equipment. Manufacturers organize their products into families, and these families define which products run on which production lines. A tight and logical product family definition is critical to your success in creating a robust flow line, which is a production line that responds to changes in mix and volume easily, with a minimum of readjustment. Failure to define your product family well leads to unexpected “surprises” when changes occur. Murphy’s Law tells us that if something can go wrong, it will, and a well-defined product family is a necessary requirement to reduce Murphy’s impact.

Product Family Characteristics

Product families often are not defined by manufacturing leadership teams. The sales, marketing, or financial departments have done this work, and have defined families with little or no regard to the flow of the product through the manufacturing processes. Traditional family definitions are usually based on the end-use or sales channels for the finished product, rather than the manufacturing processing paths and resource use of the products. In analyzing the manufacturing
paths your products follow, you must not assume that existing family definitions have to be accepted as they are today.

1. Family members in mixed-model flow lines are selected first on the commonality of their processing paths, as defined on the product’s individual Process Flow Diagram. Mixed-model lines are designed to build a family of similar products that share common manufacturing processes. By grouping products in this manner, you can optimize resource utilization and improve production flexibility.

2. A second characteristic that needs to be examined is the process work content per product. Large differences in labor or machine times among products in the same process make it difficult to achieve a smooth work flow. Although some time differences are normal and expected in a line building a mix of products, large swings in work content cause imbalances and constraints that may be very difficult to overcome. As a rule of thumb, work content times should be within a 30% range, with no individual model being greater or less than 30% of the average time. If the work content within a family can be kept within this range, line balancing is much easier. In a later chapter, you will take a look at refining family definitions for your power tools factory based on standard work content times.

3. A third factor to be considered in the definition of product families, is the degree of common materials consumed. Each product probably has some material that is unique, but a lack of material commonality between products increases greatly the amount of physical space required for material presentation, and the complexity of that material delivery. Material handling challenges alone limit the number of different models that can be produced on the same line. Some family definitions are driven almost entirely by material considerations. High volume environments must give serious consideration to the issue of material presentation, the physical space required, and the frequency of delivery. Too much variety may force you to sequence or kit the material. Kitting materials is not a show stopper, but it does involve additional material handling and line management. Note that if ideal material presentation can improve operator productivity and reduce part selection errors, then kitting and sequencing material may be well-worth the additional effort.

Building multiple products on the same line has many benefits for the flow manufacturer. A multi-product flow line can build a wide variety of products
in a small factory floor footprint. Floor space utilization is important to any manufacturer, for it alleviates the costs of brick and mortar expansion. Different products also have different sales cycles. If product lines are dedicated to a small number of products, the alternating peaks and valleys of the products’ sales cycles can lead to severe underutilization of assets, or to the “hire and fire” cycle of operators, in an attempt to match production capacity to market conditions. The larger the number of products you build on a single line, the less vulnerable you are to swings in the sales cycles.

Producing in a mixed model mode also helps reduce daily demand variability that naturally occurs for individual products. Forecasters know this phenomenon well: the forecast for families of products is typically more accurate than forecasts for individual products. On any given day, it would be unlikely that demand for all products is up. Some may be up, others down, and when you add them together, volatility smooths out. The more products you combine on the same line, the smoother the overall demand expected on a day-to-day basis.

The Process Flow Matrix

Let’s now look at how you can analyze the information available to you, and define a robust product family. In the previous chapter, we discussed the need to create a Process Flow Diagram or PFD for every product included in your line design. This process flow diagram displays the relationships of manufacturing processes to make a product. The product/process relationships aid in establishing groups of products that are likely candidates to be built on the same line, as well as other critical information necessary to create the mixed-model flow line design. The tool used, to help you display the relationships between the products you build and the processes you use to build them, is the Process Flow Matrix.

A Process Flow Matrix is a table that lists the products in rows and the processes in columns. Each cell at the intersection
of a row and a column indicates a process/product relationship. Once you have
drawn the basic grid, fill in each cell. One PFD at a time, you place an “X” in the
corresponding cell every time the PFD for a product shows the use of that process.
In the example in Figure 6.1, you have three different products. Each product has
a PFD indicating the sequence of processes the product requires. Although it is
not usual for a product to have its own unique PFD, in most cases, products share
manufacturing resources and manufacturing paths, and so they also share Process
Flow Diagrams. Every X you see on a Process Flow Matrix indicates that a product
requires the process indicated in the column heading.

Another look at Table 6.1 shows that there are some processes that are used by
all products. The processes with a large number of products are very important to
identify, since they are the highest volume processes and represent the main flow
of work. Conversely, make sure that you identify the processes with a low mix, for
those can challenge your ability to make the line flow properly.

In Table 6.1 on the following page we have created a matrix with 9 rows and 9
columns, based on the number of products and the processes documented in the
PFDs for the power tools factory. You have a potential maximum of 81 instances
of work content to be documented in detail. Notice that we have shaded a group
of products that share the same or similar process patterns, and possibly have the
same manufacturing paths. We refer to each group as a potential Product Family.

Process Commonality is your first indication, although not the only one, of
products that can be built on the same line. A process flow map is more helpful
when the manufacturing processes (columns) are organized in downstream
sequence left to right, in the order work flow and not alphabetically. The last
processes of the line are placed on the right-hand side of the matrix. Organizing
the processes in that fashion can provide you with some early indications of
the potential number of flow paths the products will follow, while answering
questions such as: Is it one line or multiple lines? Are there any optional paths that
separate from the main line at any point? Are the options mutually exclusive, or
do they share resources? Are there common resources between feeder processes?
Being aware of these issues is critical in the allocation of manufacturing resources
for the line.

How much variation of different processes should you allow, before your
family definition begins to break down? We can offer a general rule of thumb,
since the final determination requires more information than you have at this
stage of your analysis. Our guideline is to have an 80% or greater level of process
commonality within your product family. Less than this implies, that you have
many optional processes within your family, which are logically more difficult to
manage and design for.
## Process Flow Matrix

<table>
<thead>
<tr>
<th>Description</th>
<th>Mold</th>
<th>Grind</th>
<th>Motor Assy</th>
<th>Mandrel Assy</th>
<th>Elec Test</th>
<th>Harness Test</th>
<th>Pack</th>
<th>Test</th>
<th>Final Assy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part Number</td>
<td>Dril</td>
<td>Dril</td>
<td>Dril</td>
<td>SD04</td>
<td>CS87</td>
<td>OS31</td>
<td>OS01</td>
<td>CH96</td>
<td>CH09</td>
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<td>X</td>
<td>X</td>
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<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 6-1
Work Content Analysis

Each “X” in the process flow map identifies the existence of work content for that model. The work content could be labor, machine work or a combination of both. Every product/process combination will be associated with a Standard Work Definition that includes time estimates for each step, and you can sum the total time for each product and process. Populate your process flow matrix with the total standard times, as shown in Table 6.2.

Products sharing the same processes are normally good candidates for combining into a product family, but in Table 6.2 you can easily see two logical groupings of products based on work content times. Although both assembly and test are shared processes, the differences in work content times for four of the products, exceeding our 30% range rule-of-thumb, may cause you to separate and build these products on a separate line. If you attempt to mix these two groups of products, the first with average Final Assembly times around four minutes per unit, with the second group with average times around eleven minutes per unit, the work flow will be negatively impacted. A lower work content product will be done considerably sooner, but you won’t be able to move it downstream to the next workstation if that station is still occupied with a longer work content product. This is what is called a blockage. On the other side of the coin, if you complete a low work content product, but the upstream workstation is still occupied with a high work content product, you will have nothing to work on. This is called waiting. In short, too much variation of work content time makes it hard to balance the work flow. These issues are discussed in more detail, in later chapters on balance and simulation modeling.

It is important not to go overboard in defining too many families, or to think that small differences between products justifies a new family definition. Too many lines, with insufficient volume in any one line, will consume floor space and require workers to shut down one line and move to another on a daily or hourly basis. A failure to combine products well, can result in inefficient use of resources, since you normally round up the number of resources required per line.

The creation of product families is an important implementation step to ensure a successful line design. The family definition needs to be an iterative process, one that you will come back to as you continue your line design journey.

Sorting the Process Matrix

The software tool of choice in creating and analyzing process maps is a spreadsheet tool like Excel. The spreadsheet format allows you to easily create and manipulate
### Process Flow Matrix with Work Content

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Mold</th>
<th>Grind</th>
<th>Motor Assy</th>
<th>Wiring Harness</th>
<th>Elec Test</th>
<th>Mandrel Assy</th>
<th>Final Assy</th>
<th>Test</th>
<th>Pack</th>
</tr>
</thead>
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<tr>
<td>DR12</td>
<td>Drill</td>
<td>.3</td>
<td>.7</td>
<td>1.7</td>
<td>4.2</td>
<td>1.3</td>
<td>1.3</td>
<td>3.3</td>
<td>1.5</td>
<td>3.2</td>
</tr>
<tr>
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<td>Drill</td>
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<td>.7</td>
<td>2.3</td>
<td>4.5</td>
<td>1.3</td>
<td>1.3</td>
<td>12.2</td>
<td>1.5</td>
<td>6.5</td>
</tr>
<tr>
<td>DR11</td>
<td>Drill</td>
<td>.3</td>
<td>.7</td>
<td>2.7</td>
<td>5.3</td>
<td>1.3</td>
<td>1.3</td>
<td>4.1</td>
<td>1.5</td>
<td>3.3</td>
</tr>
<tr>
<td>SD04</td>
<td>Sander</td>
<td>.3</td>
<td>.9</td>
<td>2.1</td>
<td>4.6</td>
<td>1.3</td>
<td>1.3</td>
<td>3.5</td>
<td>1.5</td>
<td>3.4</td>
</tr>
<tr>
<td>CS87</td>
<td>Circular Saw</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.8</td>
<td>10.5</td>
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<tr>
<td>OS31</td>
<td>Orbital Sander</td>
<td>.3</td>
<td></td>
<td>3.7</td>
<td>4.6</td>
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<td>1.3</td>
<td>4.5</td>
<td>1.5</td>
<td>3.1</td>
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<td></td>
<td>2.3</td>
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<td>1.3</td>
<td>4.2</td>
<td>1.5</td>
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</tr>
<tr>
<td>CH96</td>
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<td>11.3</td>
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<td>CH09</td>
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<td></td>
<td></td>
<td></td>
<td>2.8</td>
<td>9.8</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 6.2
rows and columns, and to sort your data based on various criteria. This is especially useful if you have a long list of products and processes, and you want to sort the products logically by process commonality in order to define your product families. You can’t simply use the Data/Sort functionality built into Excel. The following is a step-by-step description of how to sort the spreadsheet correctly by process commonality.

**Step 1.** Add a row directly above the process names, and number them 1 through n, with n being the total number of processes.

**Step 2.** Replace each “X” in the spreadsheet with the process number for that column. Make sure that the cells are formatted as numbers and not as text.

**Step 3.** Create a column to the right of the last process, and title it “Family”. For each product row, sum the cell value to the power of the column value (cell^col). The sum statement for the seventh row, with seven processes, will look like this (without the spaces): = B7^B$2 + C7^C$2 + D7^D$2 + E7^E$2 + F7^F$2 + G7^G$2 + H7^H$2.

**Step 4:** Sort the entire spreadsheet on the “Family” column. This will group products according to the calculated values in the family column, which quantify their degree of process commonality.

Keep in mind, it is not necessary to have exactly the same family value to be included or excluded from a product family. Values that are similar are an indication that the process flow is also similar.

**Testing Your Family Definition**

One of the risks associated with using a product family grouping as a basis for your line design, is that once you get to actual production, things change. One of the things that changes is the overall production volume that you achieve daily, weekly or monthly. We’ll tackle this issue in an upcoming chapter titled Demand and Takt Time. The other parameter that changes, is the mix of products, even if the overall volume remains fairly constant. New products are introduced, old ones are discontinued, and the actual customer demand, are not within your complete control. The final validation of your product family, other than your experience of actually building products, comes further in this book, when you test your proposed design through peer review, and the use of simulation modeling tools.

Several guidelines were recommended in this chapter, to help ensure a robust family definition: maintaining an 80% or greater level of process commonality, and
keeping the work content times within a +/- 30% range. But what if these goals are not achievable? You can’t simply create another production line for every product that doesn’t meet your product family definition. This is especially challenging in a high-mix, low-volume business that has a large variability of different products, and for which the order quantity is typically low. In these types of production environments, you need to build a variety of different products using the same resources.

One key to success to help extend the boundary of your product family definition, is a high level of cross-training. If you cannot achieve a smooth balance of work, due to variability of the work time within your family, where some products take significantly longer or shorter than others to complete, you can overcome this challenge to a significant degree by having workers “move to the work”. If I’m taking longer, someone can move over and help me. If I’m done sooner, I can move and help someone else. If workers can respond in this way, they can stay productive and continue to add value, albeit by working at more than one workstation. This opportunity will be discussed in more detail in the chapter Balance, under the topic The Self Balancing Line. Asking operators to move to the work is sometimes a cultural challenge, but it’s well worth promoting.

Another option for overcoming work time differentials or lack of process commonality, is to create a multi-family line or cell, as opposed to a mixed model line. In this environment, it is necessary to build products in small batches or in order quantities, rather than mixing products as you would in a true mixed model line. It may be necessary to build in small batches for several reasons:

1. The raw material is typically delivered in a kit. While the Kanban technique is the material delivery method of choice, Kanban works best for materials that are consumed on a regular basis. Unique material, or material used infrequently, would normally be delivered when needed, and not stored in a permanent Kanban container.

2. Kanban also works best when you spread the requirements for any one product over the production day. This avoids overloading the Kanban system with the same material requirements over and over in a short period of time.

3. For medical, military or aerospace products, material and workmanship traceability requires that the order be produced together as a batch or lot. A paper or electronic traveler goes with the lot, recording the material consumed and the operator who did the work. Separating an order would make this data collection step much more difficult.
A high mix environment probably means that the operators building the products may not have worked on any particular product in awhile. Shifting from one product to another reduces the learning curve that happens by building more than one unit at a time, and productivity falls. Finally, the biggest challenge for a true mixed model strategy, is the existence of changeover time between products. This, as Toyota realized 50 years ago, is a show-stopper for single-piece-flow.

You can accommodate a wider range of process commonality and standard times, and approach the performance benefits of true mixed-model production, if you focus on quick changeovers, cross-training of the workforce and a flexible material delivery method.

A final option to extend the range of your product family definition, is to design cells or lines in sub-sections of the overall process flow. There may be portions of the flow that can be linked and balanced quite well, while other parts are more difficult or impossible. In Table 6.1 you can see that all products share the processes Test, Final Assembly and Pack. These three processes may be good candidates for a “sub-family” design, and more difficult to accomplish as you move upstream. In other words, your product family definition is not an all or nothing proposition. The more you can flow, the better, even if you can’t extend this to all processes.

Sanity Checks

What are some of the possible repercussions of failing to define your product families correctly? As you know, things change. The following results are to be expected, if you attempt to implement mixed-model production without a tight product family definition:

**Lowered Productivity.** If the line is not well balanced due to a high level of work content variability, three things will happen. In the best case, workers need to move more often. While we certainly encourage this behavior, the fact remains that moving requires some non-value-added time, and some non-value-added adjustment or setup time. Assisting at another workstation, if there is already a worker there, is also something that we encourage, but this is less productive than having a workstation to oneself. If workers are not cross-trained, and willing and able to move, work content variability in the line typically results in either running out of work or being blocked. In both cases, the worker will temporarily not be able to work and productivity will fall.

**Reduced Throughput.** Reduced throughput is directly related to the lowered productivity discussed above. Any time spent walking, getting adjusted or waiting
is time not spent building product. It’s not unusual to see a 10-20% reduction in units produced due to these factors, in a line that is not well balanced.

**Overly Complex Design.** A high number of optional processes result in a more complicated line design. Because you rely primarily on visual signals (as we’ll discuss in later chapters), the signaling system will become difficult to navigate. Think of an intersection where many different streets merge. Some of the cars have to wait, and the risk of car accidents is higher. The same thing can happen within your product flow.

**Lessons Learned**

Intelligent organization of products into logical families is an important success factor in your line design. Not all products can be combined.

Combining products into multi-product lines, as opposed to dedicated lines, yields many benefits, including demand smoothing, improved productivity and floor space savings.

Several factors are included in your criteria for family definition: common processes, common work times, and common material.

The Process Flow Matrix is your tool of choice to analyze common processes across all of your products.

Family definition is an iterative process that you return to once you have gathered additional data.

Multi-family lines may be necessary to overcome variation in process times.
When American executives returned from Japan in the 1970’s, after trying to uncover the "secrets" of the Japanese economic challenge, they brought back a concept called Takt Time. Takt is a common German word meaning rhythm or beat. Takt in Leanspeak is the rate at which products are built in a process, expressed in units of time such as seconds or minutes. For example, if we design a process to complete a product every 10 minutes, the beat or Takt Time of that process would be 10 minutes. The maximum production rate or takt, is calculated as a part of our line design, when the line or cell is originally created. The line can be run at a slower rate than the calculated Takt Time, but not faster without adding additional resources like people, machines or additional work time. Takt Time is calculated with a simple formula:

\[
\frac{\text{Effective Work Minutes Per Shift x Number of Shifts}}{\text{Demand}}
\]

or

\[
\frac{H(S)}{D}
\]

Effective Work Minutes per Day (24 hours) is determined by the hands-on time that a worker has available to work during a shift, multiplied by the number of shifts. Demand refers to the number of units or pieces to be produced in a 24-hour day for the process in question. We prefer to use a day as the unit of measure of
time, as opposed to using weeks or months. It is necessary to express our process and demand data in common units of measure, and we have chosen a *daily* time-period to reflect our goal of maximum flexibility and responsiveness.

It is important to remember, that the Takt Time or “beat” of a process needs to be calculated individually for each process. Our line or cell design could have many different processes, and each process could have a different Takt Time, depending on factors like yield, rework, optionality, the quantity required, or differences in work schedules. You are designing a line where every process can meet its Takt Time target, and all processes will be linked and balanced, although they may not have exactly the same Takt Time. This will be clarified in more detail below, with a concrete example. Takt Time will be used for a multitude of purposes:

- Takt Time establishes the maximum production rate in a process, during normal work time. We design the line to meet that capacity goal.
- Takt Time is used to balance the work to be performed, grouping the work at each workplace around the Takt Time. We use the word “around” rather than “to” because in a multi-product line the work times can vary from product to product.
- Takt Time gives you a measure of the production volume or flow rate that you need to achieve in your process design.
- Takt time is used in your calculation of required resources, to determine the number of people, workstations and machines required to support a target level of demand.
- Takt time gives production workers a better understanding of the rate they will be expected to achieve.
- Takt time is an important tool in understanding how to balance various manufacturing resources.

The goal of this chapter is to understand the inputs required to calculate takt time, including an in-depth understanding of customer demand, available work hours, and shift strategies, and to understand how takt time will be used in a Lean Manufacturing environment. We’ll begin with a discussion of Customer Demand.

**Responding to Customer Demand**

The rhythm or beat of a process refers to the ability of a process to respond to customer demand. Customer demand is simply what the customer wants to buy. In a perfect manufacturing world, you would produce whatever the customer requests in real-time, and hold no finished goods inventory. This is a pure example of demand-driven production.
Customer demand is subject to change, up and down, and you need to flexibly respond to this change. Batch manufacturing accommodates changes in customer demand by building and stocking Finished Goods Inventory. The Lean Manufacturer prefers to respond directly to customer requirements, and eliminate the risk, space and working capital investment associated with Finished Goods, by adjusting the production rate up or down as demand changes.

It is important at this juncture to clear up a common misunderstanding about takt time, and our use of the word demand. The literature on Lean Manufacturing defines demand as “whatever the customer wants to buy”. This definition works well if demand is relatively stable. But stable is not a word that comes to mind in business or manufacturing, especially in the 21st Century. The Toyota Production System places great emphasis on “level loading” their production schedules to avoid excessive changes to the production environment, but in many industries today this is simply not possible. Naively trying to “build whatever the customer wants to buy” by frequently adjusting your physical production lines is a guaranteed formula for disaster. Trying to respond to changing demand, and also run an efficient factory, is traditionally resolved in a number of ways:

- Build finished goods and respond to customer demand from a Finished Goods warehouse.
- Freeze the production schedule at certain production levels, and build finished goods if necessary to maintain that volume.
- Rebalance the line frequently to adjust to changing customer demand.

Your strategy needs to be more sophisticated, and designing a mixed model line involves designing for flexibility. You do not simply react to what comes in the door, nor do you arbitrarily set your production at a fixed volume. Instead, you put in place resources that can respond flexibly to changes in customer demand in the future, without rebalancing and without building Finished Goods. One of the key inputs to your line design, is a clear understanding of customer demand, including demand variability.

When you set out to design a mixed-model line, you do not know ahead of time exactly how many products you will build every day once you go “live”. The production volume will vary from day to day, as customers place their orders for the products they want. However, you need to make a determination as to what production capacity will be required to support your expected customer demand. You need to make an assumption of future mix and volume that you will use to calculate the number of people, workstations, and machines needed. At this stage in the line design project, you need to contact your friends in the Sales and Marketing department, to see what level of output they need from
your manufacturing line to support their sales plans. As you review production volume estimates by product, and the capacity needs for the line, the beauty of the mixed-model line design strategy becomes clearer. Your goal is to set up a series of sequential workstations that build products progressively, and are balanced to a target rate. The smoother the demand pattern, the simpler the balancing of resources will be. At the individual product level, the demand patterns could be highly variable. That product level variability would not pose a problem for a Lean manufacturer building in mixed-model mode. Since you want to design a line for future needs, and not simply base your line design on the volumes you need today, the production volume per product must be a future volume. The analysis has to include growth trends, product obsolescence strategies, new product introductions, as well as sales cycles and seasons, by product. Once a determination of volume has been completed, you must express that production volume in daily quantities.

Table 7.1 shows a scenario in which you have been provided with a forecast of annual volumes for your power tools factory. Those numbers must be expressed in daily rates, by dividing the annual volume by the number of working days per year. Let’s assume that our future factory works 240 days per year, one shift per day. Once the forecast daily volumes per product have been determined, we know what the total volume at the end of the line will be: the summation of all the individual forecast volumes.

The line design occurs process by process, and we must calculate a maximum production rate by process as well. The next step is to calculate the individual volume contributions of every product to the total production volume in a manufacturing process. We will refer to this concept as the process throughput volume. The tool we use to calculate throughput volume is the process flow matrix.

In the process flow matrix, Table 7.2, we added a column called Forecast Daily Volume where we placed the product volume figures from the table in Table 7.1. Every X in the Process Flow Matrix, indicates that the volume for that product (row) contributes to the volume for that process (column). We can calculate the throughput volume by process, by adding a row at the bottom of our process flow matrix for the process throughput volume. This additional row displays the vertical summation of all the individual product volume contributions to the process. Every time a process is affected by scrap, rework, or an option percentage, we also have to account for these volume modifiers. The end result is the target number of units that we need to build, at designed capacity per day, by process.

Let’s look at the numerator in the takt time formula, the calculation of Effective Work Minutes Per Day. There are two elements you need to understand: the time available per shift, and the number of shifts you plan to put in place.
Effective Work Minutes Per Day

The numerator in the takt time formula is the Effective Work Minutes Per Day, the time that a person or machine spends building products during a shift, multiplied by the number of shifts. We do not include time taken for lunch, for breaks or for production meetings. A person who reports to work at the beginning of a shift, and leaves at the end of the shift, probably spent around 8.5 hours or 510 minutes physically on-site. Did he spend every minute working on the line? The answer is no. The actual time that a person or machine has available for work varies from company to company, but a typical production employee normally takes two rest breaks, one lunch break, and also performs other miscellaneous activities like continuous improvement meetings, morning startup and end-of-the-shift cleanup.

Let’s calculate how many minutes are available to do work, as shown in Table 7.3. We assume that there is one 30 minute lunch break, two 15 minute rest breaks, an 18 minute continuous process improvement meeting, and approximately 6 minutes in the morning and 6 minutes in the afternoon for startup and cleanup. That leaves 420 minutes of hands-on work time available for building products on your mixed-model line. That’s the number you will use as the numerator in the takt time formula.

Shift Strategies

The available work minutes per day includes the number of shifts that you will be working, the [S] in the takt time formula. You want to take this opportunity to review and possibly revise your shift strategy at this time. There are a number of
<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Forecast Daily Volume</th>
<th>Mold</th>
<th>Grind</th>
<th>Motor Assy</th>
<th>Wiring Harness</th>
<th>Elec Test</th>
<th>Mandrel Assy</th>
<th>Final Assy</th>
<th>Test</th>
<th>Pack</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR12</td>
<td>Drill</td>
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<td>X</td>
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<td>Drill</td>
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<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
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<td></td>
<td>X</td>
<td>X</td>
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<td></td>
</tr>
<tr>
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<td>Sander</td>
<td>3.2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS87</td>
<td>Circular Saw</td>
<td>64.0</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
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<td>X</td>
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<tr>
<td>OS01</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
<td>CH96</td>
<td>Chain Saw</td>
<td>54.0</td>
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<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
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<tr>
<td>CH09</td>
<td>Chain Saw</td>
<td>46.0</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>X</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>292.2</td>
<td>3.2</td>
<td>292.2</td>
<td>292.2</td>
<td>292.2</td>
<td>164.0</td>
<td>456.2</td>
<td>456.2</td>
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</tr>
</tbody>
</table>

Table 7.2
issues to consider when setting the ideal number of shifts. If customer demand exceeds capacity on one shift, you can add a second shift rather than invest in additional equipment and floor space to accommodate the increased demand on one shift. Take a look at the advantages and disadvantages of various shift strategies in Table 7.4.

We design Lean manufacturing lines for the least possible number of shifts, with a preference for either one or two shifts. Resource utilization is better with two shifts, and this still allows a third shift for preventive maintenance and surge capacity. Running one shift, and using the two additional shifts to respond to spike demand, can be a good way to handle demand volatility. The number of contribution minutes per resource must be a reflection of the reality of the shop floor. For example:

- Is the total lunchtime really 30 minutes, or is the time in the lunch room 30 minutes?
- Do the breaks really last 15 minutes each?
- Are we the poster children for work ethic?
- How many minutes per day are attributable to machine breakdown?

Many times, a line is under-resourced because you chose to ignore the reality of the factory floor. If the number of minutes per day expected is not the 420 minutes/shift as you see in Figure 7.3, it is unlikely that you will be able to change that overnight or by the time you bring the flow line live. Management mandates that require time to implement, unless followed up by policies, will not result in magic improvements to the contribution time of people or machines. We are not suggesting that you should accept inefficiencies or unacceptable behavior, but expecting to change those simply because you announce that “we are now Lean” is a bit naive. If the number of minutes used to design the line is a lower number than current practice, make sure that you let supervisors and operators on the

<table>
<thead>
<tr>
<th>Work Time Per Day</th>
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<tr>
<td>Total Shift Minutes</td>
</tr>
<tr>
<td>- Lunch</td>
</tr>
<tr>
<td>- Breaks</td>
</tr>
<tr>
<td>- Process Improvement</td>
</tr>
<tr>
<td>- Startup/Cleanup</td>
</tr>
<tr>
<td>Total Available Per Shift</td>
</tr>
<tr>
<td>Number of Shifts</td>
</tr>
<tr>
<td>Total Minutes Per Day</td>
</tr>
</tbody>
</table>

Table 7.3
floor know that. Then enlist their help to solve the problem by eliminating waste from the process.

Calculating Takt Time

Let’s now review the takt time calculation with some concrete examples. Table 7.5 is a further extension of our process flow matrix. We expanded the matrix by adding two more rows at the bottom, one for Effective Work Minutes and another one for calculated takt time. Takt time is usually expressed in minutes per unit, but it can also be expressed in other units of measure: seconds, hours or days. Very low volume environments may even express takt time in weeks or months, although its usefulness begins to fade when the cycle for each product is very long.

It is important to remember that takt time is calculated by process, and that it can be different for each process. The factors that influence takt time include anything that impacts the formula:

- Differences in shift minutes between departments.
- Differences in the number of shifts.
- Scrap.
- Rework.
- Optional processes, as in the seat warmer example above.
- Differences in the quantity consumed.

<table>
<thead>
<tr>
<th>Shifts</th>
<th>Advantages</th>
<th>Disadvantages</th>
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</thead>
<tbody>
<tr>
<td>One Shift</td>
<td>Most people prefer working on the day shift. Plant hours synchronized with front office hours. Additional 2 shifts allowed for surge capacity and PM. Allows additional capacity for seasonal demand.</td>
<td>Fixed assets not used 2/3 of the day. Requires more floor space.</td>
</tr>
<tr>
<td>Two Shifts</td>
<td>Improved utilization of fixed assets. Additional shift available for surge capacity and PM.</td>
<td>Higher overhead cost for supervision. Front office typically not available during second shift.</td>
</tr>
<tr>
<td>Three Shifts</td>
<td>Maximum utilization of fixed assets. Minimize floor space required. Delay investment in additional plant and equipment.</td>
<td>Difficult to staff and supervise. Productivity may be lower. Difficult to schedule PM. No additional time available for surge capacity.</td>
</tr>
</tbody>
</table>

Table 7.4
<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Forecast Daily Volume</th>
<th>Mold</th>
<th>Grind</th>
<th>Motor Assy</th>
<th>Wiring Harness</th>
<th>Elec Test</th>
<th>Mandrel Assy</th>
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<th>Test</th>
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<tr>
<td>DR12</td>
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<td>X</td>
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<td>X</td>
</tr>
<tr>
<td><strong>Process Throughput (Units/Day)</strong></td>
<td>292.2</td>
<td>3.2</td>
<td>292.2</td>
<td>292.2</td>
<td>292.2</td>
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<td>0.92</td>
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</tr>
</tbody>
</table>

Table 7.5
Let’s use an automobile assembly plant as a first easy-to-understand example, to drive home the concept of takt time, pun intended. If the plant works one shift, and the total effective time per shift is adjusted down to accommodate meetings, there are probably around 400 minutes available to do work. If the goal of the plant is to produce 400 cars per day, then what is the takt time of the final assembly process? Divide 400 by 400, resulting in a takt time of 1 minute per car. What about some of the other processes that will be required to assemble the car? Each car needs 4 wheels and a spare, a total of 5 wheels per car. To produce 400 cars a day, we will have to produce 2,000 wheels. The takt time of the wheel assembly process will therefore be 400 divided by 2000, or 0.2 minutes per wheel. If defects occur and some of the cars run through the assembly line twice, that will affect the total volume that needs to be processed. Not every car requires a sunroof, so the volume for the sunroof line will be less than 400 units per day, and the takt time for the sunroof feeder line will be greater than one minute. This example illustrates the fact that although there is a takt time at the end of the line, takt time must be calculated for every process.

Misconceptions About Takt Time

There are several common misunderstandings about takt time that we are now ready to address. You have solidified your understanding of the basics, and are ready to expand your understanding of the tool.

_Takt Time Is Not Work Time._ The first misconception about takt time is that it is the same thing as work content. The phrase we often hear is “The takt time of the machine is two minutes, so we get a piece out every two minutes.” There is nothing in the takt time formula related to work content at all. Takt is simply the target or desired rate of production needed to achieve a certain number of units in a day. How long it actually _takes_ to do the work, or how fast a machine runs, is a completely separate issue. The takt time is the budget or goal only. As an example: the takt time of the final assembly process is one minute, but the work time in final assembly adds up to 28 minutes of labor. You’re going to need more than one person!

_In a Mixed-Model Line, We Don’t Balance To The Takt Time._ The second misconception has to do with the use of takt time for line balancing. The phrase we often hear is “We balanced our line to the takt time.” While this may be a true statement if you are only building one product, or you have no difference in work time between products, in general it is only true on average. In a multi-product line, where work content for individual models can vary significantly, it is
necessary to balance each product individually. The target time at a workstation for an individual product can be equal to, exceed, or be less than takt time. This concept will be explained in detail in the chapter on Balance.

**You May Not Complete A Product Every Takt Time.** The third misconception about takt time has to do with the flow of product. The phrase we often hear is “In a multi-product line, a product is completed at the end of the line every takt time.” The mental image is that of a continuously moving conveyor filled with products that drop off the end of the line, in a continuous and consistent flow. In reality, this image contains several misconceptions. First, a product will be completed every takt time only if we are running the line at full designed capacity. While this is sometimes necessary or desirable, flow lines perform best when run at *less than full capacity*. Remember from our previous discussion about demand, that you designed your line to a demand greater than your current demand? Completing a product every takt time would result in overproduction, at least for the time being. Second, since the work content in a mixed-model line is variable, the actual flow rate of products also varies somewhat and does not correspond with the calculated takt time exactly. Third, if you are running your line at less than 100% capacity, there will be unoccupied workstations in the line. During some takt time cycles, a product will not be completed because there was no operator working in the final workstation.

**Takt Time Doesn’t Change When Daily Demand Changes.** The fourth misconception about takt time in a mixed-model environment has to do with changes in daily production quantities. The phrase we often hear is “Our demand changed today, so our takt time went up (or down).” In Lean Manufacturing methodology, the takt time is calculated at the time of line design and remains fixed for the life of that design. Production volumes may go up and down, but the calculated takt time of the line does not change. We listed above all of the impacts related to changing takt time, and it should have been clear that this is not something we want to do frequently. What can change on a day-to-day basis is the *flow rate*.

**Does Takt Time Always Apply?**

It may seem slightly heretical to say so, and apologies in advance to Lean purists everywhere, but there are many cases where the takt time concept or method simply doesn’t work. The idea of a rhythm or beat originated with, and applies well to, repetitive manufacturing. Automobile, aircraft, electronics and a host of other industries are excellent candidates for this method. For the takt time concept to make sense, however, we need to ensure the following conditions:
1. A tightly defined product family. Ideally the range of work content times is within the recommended range of 30% above or below the average time.

2. A progressive, sequential build process, where work is able to flow from one workstation to another.

3. Sufficient customer demand, so that there is enough volume to run the line more or less continuously.

Attempts have been made to apply the takt time concept to other industries and environments, with limited success. The attempt to force-feed takt time into offices, job shops and custom products environments is one reason why these companies sometimes say “Lean doesn’t work here”. Our definition of Lean is not married to the method of takt time, so we are free to pursue other methods, towards the reduction of cycle time and elimination of waste.

Take, for example, a remanufacturing company that performs work in the following manner:

A completed, used product is delivered to the shipping dock. After receipt it is sent to tear-down for disassembly. What was one unit arriving at the door is now over 300 individual pieces.

4. Each piece needs to be evaluated and assessed to determine the work required to restore it to as-new condition. Sometimes very little is needed, sometimes a lot of work is needed, sometimes it’s just not repairable and a new piece needs to be procured.

5. Once the required routings have been defined, the individual parts go on their way, through processing steps like blast, machining, paint, bushing installation, plating and inspection. These resources are expensive and shared, and the idea of setting up unique cells for each logical grouping of parts is not possible.

6. The work content, even for the same piece, is highly variable. Some of the 300 pieces go through like a hot knife through butter, while others require up to 100 hours of remanufacturing work.

7. Of course everything needs to meet up at the end, in Final Assembly, in order to be reassembled back into an as-new product.

The Lean solution is not to force-fit a takt time driven line design, but to introduce a pull-based signaling method that can smooth the work flow without relying on takt time. It’s easy to see, that a calculated takt time would have little
relationship with the flow of work or line balance. This example, with a proposed solution, is described in more detail in the chapter on Balance.

Lessons Learned

In a repetitive manufacturing environment, takt time is a core Lean concept.

Takt time is calculated by dividing Effective Work Minutes Per Day by Demand.

Remember that Takt Time is calculated by process, and that every process could have a different takt time.

In office, job shop, machine shop or custom manufacturing environments the concept of takt time begins to break down. That doesn’t mean “Lean doesn’t work”. You just need to dig a little deeper to achieve your Lean goals.
Chapter 8 Takt Time Modifiers

- Work Time Modifiers
- Shift Modifiers
- Quantity Consumed Modifiers
- Rework Modifiers
- Scrap Modifiers
- Optional Processes Modifiers

In the previous chapter, we discussed the concept of Takt, the rhythm or beat of a process. Takt is the rate at which a process produces, in order to synchronize with the other processes in the line, in order to meet the desired Target Volume of finished products. The Takt Time formula, Effective Work Minutes divided by Volume, calculates the rate at which a single piece needs to be completed in a process, in order to produce the total desired volume by the end of the working day.

Anything that affects the Takt formula, either in the numerator or the denominator, will affect the result. A change in Takt changes the number of resources required, as you will learn in an upcoming chapter. Common sense tells us that if a process needs to produce more pieces in the same amount of time, then less time is available to complete each piece. The same logic also says that if you have less working time during the day, then less time is available to complete each piece. In this chapter, we will discuss all of the factors that will impact Takt, so that you can end up with a fully synchronized and correctly designed product flow. Ignoring these potential Takt modifiers will cause you to under-resource your line design.
Work Schedule Modifiers

Let’s start with inputs to the numerator of the Takt formula, Effective Work Minutes. It is desirable that every process in your line design have the same work schedule. Differences in work schedules translate into the need for Work In Process inventory, to cover the times when one process is working and the other is not. A simple formula is:

\[
\text{Time Difference Between Processes} / \text{Takt Time}
\]

which gives you an estimate of the number of pieces needed to cover a time difference imbalance. Since excess inventory is one of the Lean Seven Wastes, it behooves you to try to eliminate schedule differences. This is easier said than done, because the main reason for work time differences is a lack of production capacity. If a process is running on two shifts instead of one, it is probably because there’s not enough time available during one shift to get the work done in that process. Maintaining high utilization of expensive equipment is a strong incentive to run more shifts in a capital-intensive process.

The Takt logic is straightforward: if less work time is available, then less time is also available per unit, and the process needs to produce faster. If more time is available, the process will have a longer Takt Time, and produce slower. Time differences will cause the Takt Time to change, and also require more inventory in the line. In a subsequent chapter on Line Balancing, you will learn how to overcome work schedule imbalances with the tools of In-Process Kanbans.

Shift Modifiers

While we are on the subject of time, it is appropriate to mention that this is an excellent time to reassess your current shift policy, especially if you are currently running three full shifts. Reducing the number of shifts will cause your Effective Work Minutes to go down, along with your Takt Time. Logically this also causes required resources to go up, as discussed in the next chapter. The problem with a three shift strategy is that you have no time remaining in the day for preventive maintenance, and no time for surge capacity if needed. The standard Toyota shift strategy is to work two shifts, and have one shift available per day for PM and additional production. Of course, in a very capital-intensive plant, you would be giving up one shift of utilization of equipment by eliminating a shift, which would need to be considered. The trade-off is between flexibility and utilization of plant and equipment, and now is a great time to have that discussion with your implementation team.
Quantity Consumed

The next common-sense consideration that impacts Takt is the quantity consumed in a downstream process. If a car requires four wheels, plus a full-size spare, the wheel feeder line needs to produce five wheels in the time allowed to produce one car. If an air conditioner has two coils, the coil feeder line needs to produce a coil in half of the time allowed to produce the air conditioner, i.e. the Takt Time will be half. You are modifying the Target Volume in the Takt Time formula, and adjusting it up by the Quantity Consumed factor. A failure to make this adjustment results in a Takt Time that will be wildly wrong.

You might be tempted to set a common Takt for the wheel feeder line by calling the output of the feeder a “set” of five wheels. We discourage you from doing that for three good reasons:

1. The wheel line itself will most likely be building one wheel at a time, at a per-wheel Takt Time.

2. The quantity consumed may not always be the same. Some trucks, for example, may have options for double rear wheels, and need six wheels per vehicle instead of four.

3. The work content time for the wheel line is most likely a time per wheel. Unless you remember to convert to a full-set time, your resource calculations (coming up!) will be way off.

We will now continue our discussion of the Takt Time volume modifiers by clarifying some basic terminology, and exactly which volume you will be measuring.

Defining Terminology

Processes are affected and afflicted by rework and scrap. These volume modifiers must be accounted for in your resource calculations, to ensure that you do not under-resource the line. Not being able to meet your designed throughput, because you did not account for scrap and rework is a mistake nobody wants. The terms used in the following formulas are:

1. **Input**: The number of units arriving at the process from upstream processes.

2. **Output**: The number of good units that need to be produced by the process to support downstream processes.
3. **Throughput**: The number of units that need to be processed *within* the process, including consideration for rework and scrap factors.

The *Throughput Volume* will be used in the Takt calculations, and not the Input or Output volumes. Not using Throughput is a common mistake you won’t want to repeat. Figure 8.1 below illustrates the concept.

![Figure 8.1 PROCESS](image)

**Rework Volume Modifiers**

Rework is process yield that is recoverable or repairable. If a product is found to have a defect while still in production, that defective unit can be repaired and reintroduced into the line at the appropriate process. Here’s an example from our power tools factory, using the Process Flow Diagram for the drill product family, shown in Figure 8.2 above.

![Figure 8.2 Rework Loop](image)

These units are tested prior to being boxed and palletized. The Test process checks that every unit functions to specifications. When the drills are tested, they sometimes don’t pass. Defective units are reintroduced into the line at Final Assembly, to be worked again as another production unit. Note that there is no
“Rework” process required; the units are simply returned to Final Assembly to be reworked.

Let’s start by asking a very simple question: If you need to pack 100 good units, how many units do you have to test? Certainly more than 100, because of the impact of the failed units that need to be reassembled and retested. If you focus on the processes affected by rework, Final Assembly and Test, you see that the input to the Pack process is the same as the output of the Test process, but Test throughput needs to be higher, in order to process enough units to feed Pack and Final Assembly.

You can see the impact of using process throughput versus process output to calculate Takt. If you use output in your Takt calculation, you are missing the additional number of units that the process must work on, to reach the required output level to support customer demand. The modified Takt Time formula looks like this:

\[
\text{TAKT} = \left( \frac{\text{WORK TIME}}{\text{VOL}} \right)
\]

The “TH” is the volume “THrough” the process. To calculate the rework process throughput, you must look at the anticipated rework percentage for each product. Use the following formula to calculate throughput volume with rework:

\[
\text{VOL}_{\text{TH}} = \text{VOL}_{\text{IN}} \times (1 + \text{RWK})
\]

This formula reads as follows: “The volume through a process equals the volume input to the consuming process, multiplied by one, plus the rework percentage.” This calculation includes the individual contribution of each product to the process throughput. To do these calculations, create a version of your Process Flow Matrix, where you replace all the “Xs” with the rework percentages per product and process. Your new Process Matrix is shown in Table 8.1.

<table>
<thead>
<tr>
<th>Product</th>
<th>VOLIN</th>
<th>RWK</th>
<th>VOL\text{TH}</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR12</td>
<td>56</td>
<td>5%</td>
<td>58.8</td>
</tr>
<tr>
<td>DR54</td>
<td>84</td>
<td>3%</td>
<td>86.5</td>
</tr>
<tr>
<td>DR11</td>
<td>65</td>
<td>4%</td>
<td>67.6</td>
</tr>
</tbody>
</table>

Table 8.1

The percentages shown indicate that product DR12 fails test, and it is reworked 5% of the times, while DR54 fails 3% of the time, and DR11 fails 4% of the time. None
of the units that fail Test are scrapped. Let’s calculate the individual throughput contribution for the first three products.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Forecast Daily Volume</th>
<th>Test</th>
<th>Adjusted Daily Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR12</td>
<td>Drill</td>
<td>56.0</td>
<td>5%</td>
<td>58.8</td>
</tr>
<tr>
<td>DR54</td>
<td>Drill</td>
<td>84.0</td>
<td>3%</td>
<td>86.52</td>
</tr>
<tr>
<td>DR11</td>
<td>Drill</td>
<td>65.0</td>
<td>4%</td>
<td>67.6</td>
</tr>
<tr>
<td>SD04</td>
<td>Sander</td>
<td>3.2</td>
<td>5%</td>
<td>3.36</td>
</tr>
<tr>
<td>CS87</td>
<td>Circular Saw</td>
<td>64.0</td>
<td>4%</td>
<td>66.66</td>
</tr>
<tr>
<td>OS31</td>
<td>Orbital Sander</td>
<td>76.0</td>
<td>3%</td>
<td>78.28</td>
</tr>
<tr>
<td>OS01</td>
<td>Orbital Sander</td>
<td>8.0</td>
<td>3%</td>
<td>8.24</td>
</tr>
<tr>
<td>CH96</td>
<td>Chain Saw</td>
<td>54.0</td>
<td>5%</td>
<td>56.7</td>
</tr>
<tr>
<td>CH09</td>
<td>Chain Saw</td>
<td>46.0</td>
<td>4%</td>
<td>47.84</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>456.2</td>
<td></td>
<td>473.9</td>
</tr>
</tbody>
</table>

Table 8.2

The total throughput for the process Test is 473.9 units/day. Compare this figure with the initial 456.2 units/day. Takt for the process Test must be recalculated, based on adjusted process throughput of 473.9 units/day.

Scrap Volume Modifiers

Take another look at the Process Flow Diagram for the drill family, shown above. The process that tests the wiring harnesses, Electrical Test, is a scrap point for the line. At Test, power tools are tested and none are scrapped. At Electrical Test, the wiring harness is tested and none can be reworked. When a wiring harness is found to be defective, it is scrapped. This will force you to produce additional harnesses, to replace the scrapped units. The work to make the product is spent more than once, as are the materials. To make matters worse, all processes upstream from the scrap point are affected, unlike rework where only the products within the rework loop are. To calculate throughput volume for processes with scrap, use the following formula:

\[ \text{VOL}_{TH} = \text{VOL}_{IN} / (1 - \text{SCR}) \]

This formula reads as follows: “The volume through a process equals the volume input to the consuming process, divided by one minus the scrap
percentage.” This calculation includes the individual contribution of each product to the process’s throughput. To do these calculations, create a new version of the Process Flow Matrix, and replace all “Xs” with the scrap percentages per product and process. Your new Process Matrix is shown in Table 8.3.

The percentages shown under the process Electrical Test indicate that product DR12 fails the electrical test and is scrapped 3% of the time, while DR54 fails 2% of the time. The units that fail Electrical Test are scrapped.

Let’s calculate the individual throughput contribution for the first three products, with results shown in the table below.

<table>
<thead>
<tr>
<th>Product</th>
<th>VOL in</th>
<th>Scrap %</th>
<th>VOL th</th>
</tr>
</thead>
<tbody>
<tr>
<td>16456DR</td>
<td>56</td>
<td>3%</td>
<td>57.73</td>
</tr>
<tr>
<td>16456DR</td>
<td>84</td>
<td>2%</td>
<td>85.51</td>
</tr>
<tr>
<td>16467DR</td>
<td>65</td>
<td>4%</td>
<td>67.7</td>
</tr>
</tbody>
</table>

Table 8.3

The total throughput for the process Electrical Test is 316.98 units/day. Compare this figure with the initial 292.2 units/day. Takt for the process Electrical Test must be recalculated, based on the new process throughput. All processes upstream from Electrical Test will be affected by this increase in volume. The input volume into Electrical Test is 316.97 units/day, and this is the basis of the throughput calculation for Wiring Harness Assembly process.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Forecast Daily Volume</th>
<th>Elec Test</th>
<th>Adjusted Daily Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR12</td>
<td>Drill</td>
<td>56.0</td>
<td>3%</td>
<td>57.73</td>
</tr>
<tr>
<td>DR54</td>
<td>Drill</td>
<td>84.0</td>
<td>2%</td>
<td>85.71</td>
</tr>
<tr>
<td>DR11</td>
<td>Drill</td>
<td>65.0</td>
<td>4%</td>
<td>67.71</td>
</tr>
<tr>
<td>SD04</td>
<td>Sander</td>
<td>3.2</td>
<td>3%</td>
<td>3.30</td>
</tr>
<tr>
<td>CS87</td>
<td>Circular Saw</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OS31</td>
<td>Orbital Sander</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OS01</td>
<td>Orbital Sander</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH96</td>
<td>Chain Saw</td>
<td>54.0</td>
<td>2%</td>
<td>55.1</td>
</tr>
<tr>
<td>CH09</td>
<td>Chain Saw</td>
<td>46.0</td>
<td>3%</td>
<td>47.42</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>292.2</td>
<td></td>
<td>316.97</td>
</tr>
</tbody>
</table>

Table 8.4
Optional Processes

We discussed earlier the Quantity Consumed Modifier, and the Optional Process Modifier is a similar concept and calculation, but for work that is not required for every unit. For example, an automotive assembly line puts together sunroof assemblies, but not every vehicle requires a sunroof. If you assume that all the volume in the Final Assembly process goes through the Sunroof Assembly feeder, you would oversize the feeder process. The formula you use to calculate the impact of options is a simple one:

\[ V_{th} = V_{in} \times OPT \%
\]

This formula is read as follows: “The volume through an optional process equals the volume input to the consuming process, multiplied by the option percentage.” To do these calculations, create another version of your Process Flow Matrix, where you replace all the “Xs” with option percentages.

Spend some time building your Excel (or other spreadsheet!) worksheets based on the examples shown above, since these calculations will typically be done using that tool. Get a good feel for the impact of the various Takt Time modifiers, and how they will influence your calculations and eventual line design.

Lessons Learned

Anything that changes the Takt Time formula will change the Takt Time of a process, and the resources required in that process.

It is desirable to establish the same working hours across linked processes. Otherwise inventory to overcome the time difference will be needed.

Both scrap and rework have an impact on the Throughput Volume of a process, with scrap being the least desirable condition.

Scrap will affect the volume of all upstream processes, while rework changes the volume within the rework loop only.

Modify your Takt Time calculation worksheet to accommodate these changes to the throughput volume.
In this chapter, we introduce the concept of Standard Work through the Standard Work Definition form, with the following objectives:

• To gain the ability to calculate the number of resources in a process.
• To document the work required in a process to build a product.
• To aid in line balancing.
• To ensure safe work practices, and anticipate and eliminate hazards from the required work steps.
• To use Standard Work as a key tool in the reduction of variability.
• To support the elimination of non-value-added activities.
• To support the reduction in cost by making the consumption of material and labor more predictable, and by reducing machine breakdowns.
• To create the foundation for Continuous Process Improvement.

Given this long list of benefits and uses, it is clear that Standard Work is a central Lean tool. Standardizing work is the method used to define and organize safe and efficient tasks for every worker. Wherever work is done that is definable and repeatable, the objective is to establish a standard method for performing that work. Standard work should be owned by the people actually doing the work, and documents defining this work should be created and sustained by the operators or office personnel, and displayed in each area in a user-friendly format.
History of Standard Work

It is difficult to appreciate fully the impact of Frederick Winslow Taylor’s work on our modern way of life, since his ideas have become completely absorbed into our everyday culture. The pursuit of efficiency and the One Best Way seems to be normal and sensible. Eliminating waste has become a guiding principle in most organizations, and documenting and standardizing work is regarded as unsurprising behavior. When first introduced, Taylorism was vehemently opposed by organized labor as well as by many management groups, and Taylor was forced to defend his ideas before a hostile U.S. Congress.

Taylor won. By the 1920’s in the United States and abroad, both labor and management groups had embraced the idea. His books had been translated into over 20 languages, including Japanese, and Taylor’s approach to manufacturing, and to work in general, is known around the world. Today, the analysis and documentation of work steps and work times is a foundation discipline of Lean Manufacturing, known as Standard Work. This chapter describes the process of creating Standard Work Definitions and how they are used.

The Standard Work Definition

The documentation of standard work begins with defining the best practice for doing a job. The Standard Work Definition (SWD) is created with the goal of minimizing human effort and time, ensuring safety and ergonomic concerns, reducing ancillary waste like scrap and energy, and achieving zero defects. Workers are expected to follow the Standard Work Definitions, and are trained in their use. Descriptions of the Standard Work Definitions are posted in work areas, preferably in an easy-to-use or graphical format, emphasizing the key work steps and quality checks required. Standardization of work creates a baseline from which improvements can be made over time, and helps to eliminate process variability that has a highly negative effect on achieving consistent output.

The Standard Work Definitions should not simply come down from management. The people doing the work should have a hand in their creation, and have ownership of them. This approach has several advantages, not the least of which is that operators know the work best, and are closest to it. Buy-in of any process changes and improvements will be better if the workers originate the ideas. An environment in which new ideas can be introduced and implemented by workers themselves, can evolve the Standard Work Definitions to a continually improving level. Workers need to receive the necessary training to analyze work steps and document standard work correctly. Management must also be willing to allow this level of participation from the workforce.
The method for documenting standard work is simple: go out on the factory floor or office, observe the work within a process, and document it as a series of sequential tasks or work steps. Identify the parts consumed, and assign them to each task. Document the tools required for each work step. To document the work content time, take a sampling of times by observing a number of different operators doing the same task. Finally, interview an experienced operator to identify the quality criteria for each work step.

The scope of a Standard Work Definition covers a process, a product, or family of products. If a product shares the same work steps and times with another product, it can share the same Standard Work Definition.

The Standard Work Definition form, shown in Table 9.1 below, can be tailored to the needs of different work environments, depending on the need for specific types of information. A labor-intensive environment will be focused on the balance of labor work steps, error-proofing the process, and creating a reasonable estimate of work content time. Machine-intensive environments need to look more closely at changeover times, setup times, internal and external work steps, and precise time data. The columns needed on the Standard Work Definition form can vary. In all cases, it is important to document the detailed work steps, the work content times, the order of work steps and the quality aspects of the work. Machine and labor times are measured independently, since they can be different.

Care needs to be taken when observing and documenting work steps and times. Operators need to know what is taking place, and the reason for capturing this information. Workers should document their own work if possible, which reduces their concern that the work steps will not be documented correctly. Depending on the company environment and culture, operators being timed may either slow down (thinking that you’re out to cut their standard time), or speed up (thinking that you are measuring their individual performance). Individuals naturally work at different speeds, so gathering a sample of work times is necessary.

Simply using preexisting process documentation and standard times is not recommended, although you might use this documentation as a starting point. The Line Design is an opportunity to gather fresh information, and to get close to the work. Preexisting work times may have been adjusted by various factors, making them very different from the actual pure work time. The work steps have probably changed over time, and the level of detail in existing documentation may be inadequate. There will be data elements missing that need to be gathered. For all of these reasons, it is a good idea to take a fresh look at the work being done, and not simply rely on preexisting data.
An important reason for reviewing the standard work, is an evaluation of quality, with an eye to error-proofing the work steps. In a perfect world, a work step can be performed only one way, the right way, with no possibility for error. If this is not the case, and a mistake can be made, Murphy’s Law will rule and ways must be found to eliminate the possibility of defects, or at least catch the mistake, as close as possible, to where it occurred. Mistake-proofing the process, called *Poka Yoke* in Japanese, is always the first choice, and often simple tools or fixtures can prevent errors at a work step. Worker inspection is a requirement in cases where a possibility of error remains. This technique is called a TQM Self-Check. If necessary, this self-inspection step can be supplemented by having another co-worker check the same work step; this is called a TQM Check. By applying both a TQM Self-Check and a TQM Check, each work step subject to variability will have been looked at by two sets of eyes. Applying these simple and inexpensive remedies has an immediate and powerful beneficial effect on quality.

The application of Standard Work will have a positive impact on safety. Safety warnings can be added to ensure that the work is done according to specifications, and also in the safest possible way. The Standard Work Definition opens up a unique window of opportunity for the Lean practitioner, to analyze issues like repetitive motion injuries through data, rather than opinion or perception.

**Documenting Work Content**

This section is dedicated to the description of the various data elements needed to complete a Standard Work Definition form. Some data fields may not be needed, and can be deleted from the SWD form. It is important to understand the right level of documentation, and the right amount of detail to include in this form. Too much detail can be as bad as too little. The Standard Work Definition should be a practical document, and provide information that can actually be used.

**Header Information**

The first data required ties the SWD to a specific line, process, product or family of products. This is very important engineering-related information. The engineering department should manage the SWDs, so a formal tracking system will be needed to ensure their maintenance.

Standard work is documented at the product and process level, so both of these data elements must be included at the top of the form. The date that the SWD was created is necessary, as well as the documenter name. The data fields reflected in the sample SWD in Table 9.1 may vary according to the needs or methods of your engineering department. They define what information they want in the header.
WORK ELEMENTS AND TASK DESCRIPTIONS

The most basic element of the Standard Work Definition is the description of the work step itself. The task description should be sufficiently detailed to clearly describe the work step, while at the same time keeping the wording concise. Describe the work in as few words as possible, and write the tasks in a way that can be understood by most people. Avoid lingo and acronyms, and do your best to spell out every word. Put yourself in the shoes of a new operator and ask “Is this understandable?” Try to keep work elements as short as possible, without documenting individual motions. In general, the individual motions, “extend arm” for example, are considered part of the work content or task itself. Sometimes traditional time-and-motion studies, taught in some college programs, go overboard, as illustrated in Table 9.2. Compare this to the higher-level detail appropriate to a Standard Work Definition.

ORDER

The order is the sequence in which the tasks should be done. This column defines the sequence of work steps in a process. These are normally performed one after the other, but there may be exceptions, especially when documenting a process with more than one operator working at the same time and place. If more than one person is performing work at the same workstation, you must ask if a single person could do the work alone. If the answer is yes, document all the steps performed as sequential tasks, as if done by one person. If the answer is no, document the work of each person in separate tasks, indicating that they overlap.

PREVIOUS WORK STEP OVERLAP

If all of the work steps are sequential, one after the other with no exceptions, then this data element is not needed. It is common, however, to document concurrent or overlapping work tasks. For example, on a large product it is possible to have two or more people working on the unit at the same time. The previous work element can be used to correctly document overlapping or out-of-sequence steps. In some cases, project planning tools have to be used to identify the critical path through a lengthy Standard Work Definition with multiple overlapping tasks. This critical path is later used in the creation of workstation definitions as the backbone of the line designs.

PARTS CONSUMED

A product Bill of Material is not structured according to where the parts are consumed in a specific task or work element. Traditional multi-level Bills of Material are structured by subassembly part number, and not at the more detailed
### Standard Work Definition

**Process:** Final Assembly  
**Product:** HR 55  
**Multi-Product Flow Line:** Air Moving  
**SWD Name:** FA-HR 55/57

<table>
<thead>
<tr>
<th>Order</th>
<th>Overlap</th>
<th>Description</th>
<th>Code</th>
<th>Part Number</th>
<th>Material</th>
<th>Qty</th>
<th>Machine Setup</th>
<th>Machine Run</th>
<th>Labor</th>
<th>TQM Check</th>
<th>Self Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td>Retrieve fixture from under the conveyor</td>
<td>DS</td>
<td></td>
<td>Work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>Retrieve stator and place in fixture</td>
<td>DS</td>
<td></td>
<td>Work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>Insert wire - exit grommet</td>
<td>W</td>
<td>6672 bracket</td>
<td>Material</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>Attach mounting bracket with 1 screw</td>
<td>W</td>
<td>2042 screw</td>
<td>Material</td>
<td>0.3</td>
<td>Install on wire exit side</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>Repeat step 40 once</td>
<td>W</td>
<td>2042 screw</td>
<td>Material</td>
<td>0.1</td>
<td>Screw gun set to “3”.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>Retrieve top shield and install with 1 screw</td>
<td>W</td>
<td>1068 screw</td>
<td>Material</td>
<td>0.6</td>
<td>Bearing is greased and grease fitting is tight. Set screw gun to “5”.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>Repeat step 60 once</td>
<td>W</td>
<td>1068 screw</td>
<td>Material</td>
<td>0.1</td>
<td>Screw gun set to “5”.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>Insert rotor guide into stator</td>
<td>DS</td>
<td></td>
<td>Material</td>
<td>0.2</td>
<td>Do not scratch coils.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td>Retrieve rotor and install in stator</td>
<td>W</td>
<td></td>
<td>Material</td>
<td>0.6</td>
<td>Long side of shaft first. Check for free turn. Set screw gun to “5”.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>Retrieve bottom shield and install with one screw</td>
<td>W</td>
<td>1068 screw</td>
<td>Material</td>
<td>0.6</td>
<td>Bearing is greased and grease fitting is tight.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TOTALS:** 1.2 2.8
work step level. The material presentation strategy, is to store or deliver all of the material required at each workstation. This will be accomplished using a variety of techniques that include material Kanban and sequencing methods. As work steps are grouped into workstations, capable of working to takt time, the required material necessary to do the work needs to be identified.

It is important to capture this detailed material information at the same time that the standard work elements are being documented. Otherwise you will need to do it later. This is the approach of practitioners that rush to a line design without much regard for a sound material delivery strategy. This can result in an unnecessary amount of after-the-fact work, and guesswork that is very likely to cause a suboptimal line startup. Warning: don’t underestimate the work required to create a complete and accurate material delivery plan!

**Quantity**

The quantity of each component part consumed when performing the related task needs to be documented. This quantity may be less than the Bill of Material quantity, since the same component may be consumed at other workstations as well. The availability of this data will be needed to calculate Kanban and sequencing quantities to each workstation. Individual usage will be a part of the Kanban calculations as the Line Consumption Factor, one of the elements of the Kanban formula.

**Work Content Time**

Time estimates need to be documented for each task, by observing the work being performed, and timing the work with different operators. It is not recommended to simply use the company’s existing time standards, but rather to gather fresh information through direct observation.

Document the type of work being done. Is this task a setup step, a value-added work step, a move or transportation step? This information will be used for process improvement, cost reduction, and line balancing. The Standard Work Definition form in Table 9.1 demonstrates the use of different columns to capture different types of work. Following are the work content time classifications displayed on the SWD, and their purpose:

*Machine setup time:* Setup time is always defined as time spent preparing to do work. During setup tasks, the product is not advancing towards its point of completion, and value is not being added to the product itself. Setup is not the same as changeover time. Changeover is time spent preparing a machine for a run of more than one part (a batch). Setup time occurs for every piece, or on every cycle. Two subcategories of machine setup time are:
Machine setup attended time: A person and a machine are being used concurrently during this task. Capturing the Labor and Machine components ensures a proper resource calculation later. Example: loading a piece of bar stock onto a lathe, which requires both a person and a lathe.

Machine setup unattended time: The machine is set up with no operator intervention. Example: Automatic loading of a part into a press brake.

<table>
<thead>
<tr>
<th>Order</th>
<th>Time and Motion Study</th>
<th>SWD</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Reach for bracket with right hand</td>
<td>Attach bracket with one screw</td>
</tr>
<tr>
<td>20</td>
<td>Retrieve bracket</td>
<td>Repeat previous step</td>
</tr>
<tr>
<td>30</td>
<td>Reach for screw with left hand</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Retrieve screw</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Place bracket in position</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Place screw in hole over bracket</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>Reach for air driver down to meet screw</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>Attach screw to bracket</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>Reach for second screw with left hand</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Place screw in hole over bracket</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>Bring air drive down to meet screw</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>Attach screw to bracket</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>You can breathe now</td>
<td></td>
</tr>
</tbody>
</table>

Table 9.2

Machine run time: Run time is conversion time during which value \textit{is} being added to the product. A machine cycle typically results in one or more units of product being completed. Two subcategories of machine run time are:

Machine run attended time: Operator and machine work concurrently.

Machine run unattended time: The machine is working without operator intervention. Separate labor and machine time, so calculations of people and machine resources give an accurate analysis of the resource needs per process.

Labor setup time: These are steps of work done in preparation for conversion tasks. Tasks under this category have no machine intervention at all. Example: The operator has to unwrap a part before installing it into the product.
**Labor conversion time:** This is the time spent by one or many operators adding value and advancing the product towards its point of completion, using labor time, parts, and tools.

In Chapter 10, we use the Standard Times extracted from the Standard Work Definitions to determine the number of required people, machine or inventory resources for the designed production volume. We also discuss what to do when you don’t have work times available. We provide some recommendations on how to go about obtaining those, to ensure a sound design.

**TQM Self-Check**

A self-check is a quality inspection step that is documented on the Standard Work Definition when an element of work contains process variability, i.e. it is possible for the work to be performed incorrectly. The self-check is the responsibility of the operator who did the work. Part of the operator training process is to ensure that any required quality checks are clearly understood, and are able to be performed correctly. The quality criteria and the points being inspected are described in this SWD element.

The assessment of the need for a quality check is done for each task on the SWD. The first goal is to eliminate process variability. Process variability means having more than one way to do the work, while only one is correct or best. Follow this rule: you document quality criteria for a task every time there is more than one way possible to do the task, but only one is correct. The consistent use of these instructions within the context of the Check-Do-Check technique will yield great improvements in workmanship quality.

**TQM Check**

This is a second inspection that is performed to double-check that a work step has been done correctly. The TQM Check is the responsibility of the next operator downstream in the flow. If the product is found to be defective, the piece is returned to the person upstream who originally performed the work step, and that person must fix the problem. Note that the person who originally performed the work should have done a self-check as well, but often the person doing the work fails to detect a mistake that a fresh set of eyes will catch. For critical quality steps, you need a second person to perform a TQM Check; you can’t rely on just one set of eyes.

Checking this column on the SWD indicates that this work step is critical enough to require an inspection by two sets of eyes. This check would be completed before performing any other work steps at the second station.
The Check-Do-Check technique builds on the common knowledge that two sets of eyes on the same task are more likely to catch mistakes than just one. A common example of this is the need to proof-read written material. It is always more likely that somebody other than the author will catch typos and mistakes. These simple quality tools are a powerful way to mistake-proof a process and product. The predictable and consistent application of the Check-Do-Check technique puts the line workers on alert to pay attention to and identify opportunities for improvement in the product design itself, as well as in how the work is done.

The expression “parts-per-million” refers to the achievement of a very high level of quality, using quality tools. This is not reached with a single tool or method, but the tool derived from the SWDs is the Check-Do-Check technique. Check-Do-Check has the potential for eliminating workmanship errors. Let’s analyze the rationale behind it.

Even a person trying to do a good job will make mistakes. As Deming instructed in his famous Fourteen Principles, slogans like “Do it right the first time” are useless in improving quality. A person trying to do a good job will still make mistakes at a certain frequency, determined by the difficulty of the work and the number of repetitions.

Assume, that George is performing a repetitious task that results in one bad unit for every ninety nine good ones. Errors occur at a 1% rate. As part of the standardized tasks at his workstation, George is required to check specific quality points for his own work. The work for George has been expanded from simply “assembling” into also “checking my own work”. With the same 1% error rate, George is likely to catch 99 of every 100 errors, letting one defective unit per 100 go through.

Sally, who receives the output of George’s work, also checks specific inspection points in the product. The new work here is defined as “looking for George’s mistakes”. This second person works at the same level of quality as George, and also misses 1 of every 100 errors. Let’s now see how the probabilities look:

$$\frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} = \frac{1}{1,000,000}$$

George x George x Sally = one defect per million repetitions. This is better than a Six Sigma quality level.

If we assume a more pessimistic 3% error rate, we get:

$$\frac{3}{100} \times \frac{3}{100} \times \frac{3}{100} = \frac{27}{1,000,000}$$

or twenty seven defects per million repetitions. This is still not too shabby.
In actual practice, results will vary. The use of a simple method like Check-Do-Check can result in great improvements in quality, at a low cost.

**Value-Added Work Elements**

A value-added work element, is a work step that advances the product closer to its point of completion, or adds value to the product in the eyes of the customer. Non-value-added (NVA) work is a work step that *does not* advance the product closer to its point of completion, or does not add value to the product in the eyes of the customer. Common examples of non-value-added work steps include setup, inspection, testing and move work, unless the customer is willing to pay for those steps directly. Formally classifying tasks as value-added or non-value-added serves several purposes:

1. The classification provides some idea of the size of the improvement opportunity. Calculate the amount of non-value-added work, as a percentage of the total, and you may be surprised at the amount of waste hidden among the work steps.

2. The NVA work elements can be incorporated into your checklist of future continuous improvement projects. The elimination of non-value-added work steps does not require the approval of design engineering, as long as these changes do not physically change the product itself. A process improvement team usually focuses on the elimination of non-value-added work steps, but if the NVA work step is easy to eliminate, do it!

3. The classification also gives direction for the design engineering department when they redesign a product. A list of NVA activities and self-checks indicates to the engineers that waste is being driven by the product’s design.

**Move Distance**

If the product must be moved from one place to another, this data element documents the distance, in feet, yards or meters. Movement from one workstation to another may or may not be included as a separate task, depending on the overall takt time and distance required. In a high-volume environment, the movement of product can represent a significant percentage of the total work time, and should be documented separately.

A curious aspect of the issue of documenting distance is that it is either blown out of proportion by inexperienced Lean practitioners, or ignored by more seasoned ones. Keep your eye on the cumulative effect of distance. If you can save a few walking steps for an operator, who must repeat those steps many
hundreds of times a day, that is a positive goal. Although the distance reductions are unlikely to have a significant effect on key Lean project metrics, when you get down to chasing the next one percentage point of increased productivity, every little bit counts. One very commonly-used tool in reducing the distance traveled by operators, is the U-shaped line configuration. This arrangement of equipment allows for a person to operate multiple machines, while minimizing the walking time from machine to machine.

**CHANGEOVERS**

A changeover is the work required before running a batch of parts on a certain machine. Changeovers apply almost uniquely to machine-based work. The difference between a setup and a changeover, is that a setup occurs once every cycle or every piece, while a changeover is done once, to run many pieces. The reason for differentiating between a changeover and a setup, is that changeover time is not considered in the resource calculations, while setup time is.

Changeovers can be classified as either external or internal. An internal step must be performed while the machine is stopped, while an external step can be done while the machine is still running on the previous job. A basic technique of changeover reduction, is to convert internal steps to external ones. Although an external work step still needs to be done, and is still non-value adding, it does not occupy the machine directly and is therefore much preferred.

**Writing Standard Work Documents**

When documenting Standard Work, let your common sense guide you. Be realistic with the task times. Lean Manufacturing is not intended to be a labor reduction or labor efficiency program; productivity gains come as a result of a focus on flow and balance, and with the elimination of non-value-added steps. The big costs for most products are material and overhead, not labor. There is a tendency in manufacturing to be obsessed with labor reduction, if for no other reason than it is an easily controllable cost element. Direct labor costs are not ignored, but it is important to keep a proper focus on the overall strategic goals of customer response and quality.

What level of detail is appropriate for the work steps on the Standard Work Definition form? How far should one subdivide the process? If you get too detailed, with only seconds per task, you end up with too many work steps and a daunting documentation job. Five hours of total work content documented in 10 second increments results in 1,800 tasks and a book the size of *War and Peace*. Not enough detail, on the other hand, makes it difficult to balance the work, and does not give
sufficient visibility of the quality aspects of the work. The right level of detail is driven by the expected target volume of the line, and the total work content of the product. It can take over 500 labor hours to build a rail car, and much of this work is welding. Individual work steps, in this low-volume environment, can be several hours in length. High-volume electronic assembly lines, by contrast, need to complete a product every 30 seconds. In this environment, the Standard Work Definition needs to be extremely detailed if you have any hope of balancing the work. For most office or manufacturing environments, measuring tasks in minutes and fractions of minutes is sufficient and the right level of detail. Applying common sense to the level of process documentation detail needed, is an important success factor in the implementation project, and in being able to complete it in a timely fashion.

Video recording a person at work for the purpose of documenting Standard Work Definitions is very useful. The video gives you the ability to review the work as many times as you need, to get the best possible description of the work. You can look at the work element’s nuances, and the times are recorded for you, with no need for a stop watch! When video is used in a controlled environment, you can have experienced operators explain what they are doing as the work is being performed, creating a powerful training tool. On the downside, if you think that having a stopwatch-bearing industrial engineer looking over your shoulder is distracting, think about the impact a video camera might have. This is not an insurmountable hurdle. It just tests how well you communicated with the operators about the Lean project.

There is no doubt that the development of standard work takes a substantial amount of time. What happens to the idea of Rapid Improvement if you’re spending all your time documenting Standard Work? There really isn’t a good shortcut for understanding the processes in detail, but a Lean line design can be introduced more quickly, by using educated estimates of process times. Using an estimate of work time, rough-cut resources can be calculated and an initial flow line put in place. The standard work detail needs to be completed, but at a later time. In this way, the Lean benefits of a flow line can be enjoyed more quickly. Be prepared for more adjustments and more redoing of the line using this approach.

Standard Work needs to be communicated properly to the operators. This chapter has presented a document, the SWD, that describes every step of work, its sequence, the materials and tools required, the time it takes to perform the work, and instructions on how to check the results. Every person must follow the SWD when building products. Will you require the operators to read it every time the product comes to them? Will you provide some graphical means to quickly glance
at the work content and quality steps, or will just a reminder of the quality steps be enough? These questions will be answered in the following chapters.

**Lessons Learned**

Standard Work is not a straitjacket, but a way to establish a baseline for further improvement.

The Standard Work Definition is an excellent tool to capture the work content in its current form.

The Standard Work Definition can be used for a variety of purposes, from being the data source for line design resource calculations, to a focused guide for continuous process improvement initiatives.

The Standard Work Definitions must be properly tracked and maintained once created. Your Engineering department is already very good at that.

The Standard Work Definition form may be tailored to suite your own work environment.

Documenting the work with the objective of standardizing, is a requirement of the Lean Manufacturing processes, administrative processes, healthcare processes, or any other processes to be improved.

It is possible to rely on work time estimates to move more quickly on a line design project. The trade-off is the need for more adjustments after the line is brought live.
Chapter 10 Resources

- The Resource Calculation Formula
- Final Resource Calculations
- Weighted Average Standard Time
- The Manufacturing Cell

As you progress through the steps of data gathering, analysis, refinement and calculations, you are moving closer and closer to a detailed understanding of your physical line design. The next step in your journey, is to mathematically calculate the required resources, people and machines. The resource calculation formula compares the amount of time needed to complete one unit of work in a process (the work content), with the time budgeted or allowed (the Takt time). Here is the formula:

\[
\text{RESOURCES} = \frac{\text{STANDARD TIME}}{\text{TAKT}}
\]

Resources come in many forms. They can be people, machines, workstations, products, shelves for cooling hot products, or parking positions. Machines can be single or multi-spindle, and they can process batches continuously, or a single piece at a time. People resources are similar. There are people dedicated to machine setup or changeover, maintenance, and many other operator types.

As with the takt time calculation, resource calculations are performed process-by-process, and your focus is on one process at a time. A process has only one takt time, but the same process can have many different products flowing through it, and each product could have a different Standard Time. The numerator of the resource formula calls for one Standard Time; but which one? The longest
Standard Time? An average Standard Time? The solution to this dilemma is what you will learn in this chapter.

Once you have completed the calculations for required resources, you compare your results against available resources, and move to the fun part, conceptual line design. This is the part that everyone enjoys, because it gives the design team a chance to make bold changes on paper. Team members can get as creative as they want. Finally, the conceptual design must be converted to a CAD drawing, to incorporate shop floor realities like odd-looking rooms, columns, availability of services, ergonomics, safety, and other details.

Resource Calculations

Since you now know how long it takes to do the work, the standard work content time, and how frequently you need to complete a unit to meet target volume, takt time, you are ready to proceed to the next step in your design process, the calculation of required resources. The inputs for the formula come from the data you have already gathered:

1. Takt time calculations, by process.
2. Work content times, by product and process, from the Standard Work Definitions.

There are some subtleties to this calculation, as simple as it is. The result tells us the number of resources required, to produce the designed volume of the targeted products. But what kind of resources are they? That depends on the type of resources you have documented in your Standard Work Definition, used in the numerator of the formula. If the labor time is 3.4 minutes per piece, and the takt time is 1.5 minutes per piece, then the number of labor resources will be calculated as:

\[
LABOR\ RESOURCES = \frac{ST}{TAKT} = \frac{3.4 \text{ MIN}}{1.5 \text{ MIN}} = 2.26 \text{ PEOPLE}
\]

Similarly, if the machine time in a process adds up to 12.7 minutes, and the takt time is 3.5 minutes, then the number of machines required are:

\[
MACHINE\ RESOURCES = \frac{ST}{TAKT} = \frac{12.7 \text{ MIN}}{3.5 \text{ MIN}} = 3.63 \text{ MACHINES}
\]

What kind of machines or types of labor resources are documented in the Standard Work Definition? The formula doesn’t need to know this information, but you do. If more than one type of machine or labor classification is included in
a single process, then the resource calculation needs to be done independently for each unique resource and work time. It is very important that you review and properly interpret the results of your calculations. Failure to do so, may result in a sub-optimal line design. The Standard Work Content Times, that affects the result of a calculation of required resources, are listed as follows:

1. Labor
2. Machines that process one unit per cycle.
3. Machines that are fed one unit at a time, but have multiple units being processed in the machine.
4. Machines that process one batch per cycle.

The first case is self-explanatory. If the numerator of the formula is the labor standard time extracted from the Standard Work Definition for the process, then the result of the calculation is the number of labor resources. To calculate the number of workstations, where these people work, you simply round up the number of labor resources.

<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Calculation Result</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single piece</td>
<td>Number of Machines</td>
<td>Lathe, Single-spindle drill, Mill</td>
</tr>
<tr>
<td>Single piece feed - Continuous Flow</td>
<td>Number of units of product inside the machine</td>
<td>Powder coating system. Hang one unit of product at a time and off-load one at a time, while there is a batch inside at all times</td>
</tr>
<tr>
<td>Batch Machine</td>
<td>Number of units of product inside the machine</td>
<td>Must place a buffer equal to the number of calculated units upstream and downstream of the batch machine</td>
</tr>
</tbody>
</table>

Table 10.1

For the machine calculations, you need to pay more attention, as shown in Table 10.1.

Batch machines often have the “see-saw effect”. In order to have a full batch of units to load into the batch machine, you must accumulate them on the upstream side of the machine, while the batch inside is being processed. As an example, assume that a kiln takes 12 hours per cycle to process a batch of products. If the calculated takt time for the process “Kiln” is 20 minutes per unit, then the calculation is:
RESOURCES = ST/TAKT = 720/20 = 36 UNITS

The minimum capacity of the kiln is 36 units, to achieve the necessary production rate. It is also necessary to have enough physical space for 36 units on both the upstream and downstream sides of the kiln. In this way, during every 720 minutes (12 hours), 36 units will accumulate in front of the kiln. At that moment in time, the 36 units inside the kiln are done, and placed on the downstream side of the kiln. These 36 completed pieces are now available for downstream processes to consume them. At time zero, you must have 36 units waiting in the upstream buffer. The 36 units in the upstream buffer are then placed in the kiln. During the 720 minute kiln cycle, units accumulate in the upstream buffer, at a rate of one every 20 minutes (takt). At the end of the next 720 minute cycle, the units exit the kiln and are placed in the downstream buffer, and the 36 upstream units are placed in the kiln. This empty-fill cycle repeats itself every 720 minutes.

Weighted Average Standard Time

In a mixed-model line, it is possible that different models will have different work content times. We discussed in the previous chapter the need to assess your product family definitions in light of differences in work content times. Even within a well defined family, there will be differences. How is this variation handled in order to calculate required resources? A single time is needed in the numerator of the resource formula. You could have a different work content time for each product, but you still need just one single value in the required resources formula. The solution is to calculate an average time using a weighted average, with throughput volume per product as the weighting factor. You multiply each work content time by its corresponding throughput volume for that product, add up all of these values, and divide by the total throughput volume. The resulting formula for the weighted work time is:

\[ STw = \frac{\sum (ST \times VOL)}{\sum VOL} \]

The \( \sum \) symbol means “sum”, VOL is throughput volume and ST is the standard work content time for each individual product. The weighted average work time is then used in the resource formula, and the adjusted formula is:

RESOURCES = STw / TAKT

The weighted average work content time only needs to be used when there are work time differences in the products, within the process. If the times are
all the same, no weighted average calculations are needed. Now is when you
 go back to the Process Flow Matrix, and replace the “X” that displays a product
 and process relationship, with the standard times per product, from the Standard
 Work Definitions. Since it is possible that a process has both labor and machine
 resources, you subdivide each column in the process matrix into two columns,
 one for labor and one for machine standard times. This is the second version of
 your Process Flow Matrix, referred to as the Standard Time Matrix, as displayed
 in Table 10.2 below. We have added three new rows at the bottom of our standard
 time matrix, for weighted standard time, calculated resources, and number of
 workstations or physical locations. The calculation of resources needs to be done
 independently for machine and labor resources for each process.

 Chances are excellent that your resource calculation will not be a whole
 number, as we saw in our examples. Most likely the number will include a fraction
 of a resource. Don’t make the mistake of automatically rounding up to the next
 highest integer, so that the calculated 3.23 people for the wiring process become 4
 people, or 2.63 people become 3 people automatically. Before you round up, you
 need to take a look at a few things:

 1. Check the standard times from the SWDs, to see how stable they are. The
    higher the variability in the standard times, the higher the likelihood of
    having to round up.

 2. Review the non-value-added work elements in the SWD. Make an effort
    to improve the process by eliminating non-value-added work steps. Many
    times, the elimination of setup or transportation steps leads to a reduction
    in the process standard time, which enables you to round down.

 3. Ask yourself if some of the work steps can be relocated to processes that
    need to be rounded up, but still have some headroom with respect to the
    process takt time.

 4. Trust your gut, and weigh the impact. Sometimes, the numbers do not give
    you all the answers, so you must make educated assumptions and move
    forward. If your gut tells you to round down, go ahead and do so. Just
    make sure that you leave enough room for correction.

 As a rule of thumb, look at the number of calculated resources and evaluate
 fractions of a resource in three ranges: under 30%, between 30% and 50%, and over
 50%. Remember that you expect to gain productivity and process improvements,
 and rounding up every resource could short-circuit some of your expected
 benefits. Even if you decide to round up the number of workstations, you would
 not round up the number of actual workers. With a cross-trained workforce, you
could have fewer workers than workstations, and the workers have to cover all of the necessary workstations, to do work as required. We will discuss this strategy in more detail later.

The second to last row of our standard time matrix, in Figure 10.2, shows the results of your resource calculations. These are the number of resources, machines and workstations that you will include in your initial line design. You may find that adjustments are necessary once you evaluate line balance and line flow. The last row of Table 10.2 establishes the number of physical locations in your line. For labor-only processes, the locations represent physical workstations or places where operators do work. Machine locations represent the machines themselves, separate from the human operators. The total number of locations defined on the Standard Time Matrix is 28. Adding the exact number of labor resources, including the fractions of a resource, you get 20 people. Simply putting a person at each physical location, as we might traditionally do, results in serious over-staffing and low productivity. Flow lines have higher productivity, when there are some empty workstations during normal operation. These empty workstations, or “holes” in the line, help absorb some of the unavoidable delays, that occur in a mixed-model line. The 20 workers manage 28 locations, by moving to where the work needs to be done. As long as the workers add value continually, the daily production volumes will be accomplished.

You are drawing closer to assembling the preliminary line layout. But before that momentous occasion, you need to do more analysis of your calculations, to make sure that you transition into the physical line layout with the best information.

**Final Resource Calculations**

We have included the impact of rework, scrap, and options on takt, as discussed in the previous chapter. You are now ready to complete the resource calculations. You proceed process by process, and calculate the number of people, workstations, and machines needed. Once this step has been completed and validated, you will be ready to put together a conceptual line design on paper, so the team can agree on how the flow line will function.

**Manufacturing Cells**

A manufacturing cell constitutes a group of resources dedicated to a specific group of products that share some commonality. Sometimes the characteristics of the products prevent us from combining them on the same line. You always start by trying to combine as many products as possible on the same line, but there are factors that prevent you from doing so. Process commonality was the main factor
<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Forecast Daily Volume</th>
<th>Mold</th>
<th>Grind</th>
<th>Motor Assy</th>
<th>Wiring Harness</th>
<th>Elec Test</th>
<th>Mandrel Assy</th>
<th>Final Assy</th>
<th>Test</th>
<th>Pack</th>
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<tr>
<td>DR12</td>
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<td>0.7</td>
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<td>0.7</td>
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<td>0.7</td>
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<td>1.5</td>
<td>3.3</td>
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<td>0.9</td>
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<td>1.7</td>
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<td>1.3</td>
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<td>2.56 0.92 0.92 0.92</td>
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<td>2.63</td>
<td>0.92</td>
<td></td>
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</tr>
</tbody>
</table>

Table 10.2
used to determine product families when you analyzed the Process Flow Matrix. You defined a family as a group of products that shares the same, or very similar, processes. Your analysis does not stop there.

The next factor that you need to evaluate is work content time. By definition, a process can only have one takt time, but it works on a mix of products that have different work content times. If the range of times is too great, it will be difficult to maintain a smooth work flow, and the process will have a hard time delivering products at an average takt time. You need to separate the process into two, in order to group products with similar content times.

Finally, you need to assess the impact of materials on the ability to manage a mixed model product family. It is desirable to share common materials among the various models in our product family, in order to reduce the complexity of material delivery. While anything is possible, too much variation in materials will drive up your material management cost.

Using Resource Calculations

The output from this stage in the Mixed Model Line Design method is a resource calculation worksheet that shows, by process, the people and machine resources required. This is one of the two essential documents that you need to have in front of you, in addition to the Mixed Model Process Flow Diagram, as you embark on the creative task of creating a Preliminary and Final line layout.

One final point: note that the resource calculations done so far are static calculations that do not take into consideration the impacts of process variability, product time variability, and product sequencing. It may be necessary, upon further testing, to add additional resources in order to overcome these challenges. A chapter in this book on Simulation analyzes these factors in more detail.

Lessons Learned

Single-piece flow is the main goal, but it is not always attainable. Sometimes, you need to flow batches.

Resource calculations are done one process at a time.

Analyze the resources per process, under the light of standard time commonalities. If standard times are too different within a process, consider created sub-lines or cells.
Chapter 11 Achieving Balance

• BALANCING WORK
• ELIMINATING WASTE
• RELOCATING WORK
• ADDING RESOURCES
• ADDING IN-PROCESS KANBANS
• INVENTORY PLUS TIME
• CREATING MACHINE CELLS
• THE SELF-BALANCING LINE
• BALANCING WITH POLCA

Physically linking manufacturing processes together, so the completed output of one process can be directly consumed into the next, dramatically reduces inventories and cycle times. In a traditional batch and queue environment, little attention is paid to balancing or synchronizing the flow of work between work centers or departments. Since delays, bottlenecks and a substantial amount of WIP inventory is the norm, imbalances in the work flow are absorbed through delay and inventory. Traditional functional departments and work centers are formed by grouping together similar types of work and machines. This helps with organizational control and the collection of performance, routing, and inventory reporting data. Similar work and machines are physically placed together in one area of the facility, and in most cases this grouping of work or machines provides little consideration for the equal distribution of capacity.

Flow lines overcome the waste of delay and excess inventory, but you must address the challenge of balance in order for the line to flow smoothly. The attempt to link various processes together invariably requires analysis, to ensure that the material or information moves from one workstation or process to another, without delay. To begin with, where possible, all the processes necessary to build a product are physically connected. The physical arrangement of the resources is important, because it allows work tasks to be distributed, accumulated, and balanced evenly throughout the entire manufacturing cycle. Physically relocating
the resources greatly reduces non-value-added move time, and also helps the communication and feedback process between workers.

Balancing around a takt time and physically linking manufacturing processes together, so the completed output of one process can be directly consumed by the next process, dramatically reduces inventories and cycle times. Because manufacturing processes are divided into equal elements of work, grouping of similar labor and machines into independent departments is no longer necessary. Only the resources necessary to build the products are placed on the line. By eliminating imbalanced departments, pools of work-in-process inventory cannot accumulate. By balancing and linking all processes, products are built in their work content time only, since the normal wait and queue times, for products routed in batches through the different manufacturing departments, is eliminated.

**Mixed Model Balance**

Traditional Lean literature suggests that you balance work to a calculated takt time. For example, if your takt time for a process is calculated to be 20 minutes, and you calculate that you need 5 assembly workstations, you would attempt to allocate no more than 20 minutes of work to each workstation. In theory, you should be able to flow work at that rate, and complete a unit every 20 minutes. Using your Standard Work Definition, you add up the work times until you get close to 20 minutes, and that’s the work that you allocate to the first workstation. You continue in this manner until the work for each station has been defined. The breaks in the work need to make sense, and they need to be physically possible. So far, so good.

You start running into problems, when you attempt to allocate work steps for a mixed-model line. The work steps and the work times are not always the same for every product in a family. You attempted to stay within a range of 30% when you defined your product family, but there will be differences. Some products will be over the average time, and others will be under. Trying to balance every product to the average takt time, using the method described above, will result in either too much work at the last station, or possible no work at all! Instead of balancing the work time to the takt time, in a mixed-model line, you need to balance the work *by product*, to a time target that is calculated by dividing the total work time for that product and process, by the number of workstations.

\[
\text{Product Standard Time} = \frac{\text{Product Standard Time}}{\# \text{ of Workstations}}
\]
This number will not be the takt time, except by coincidence, but a value similar to it, either above or below. If the Standard Time is above the product family average, your time target will be greater than the takt time. How, you might ask, can you meet your takt time if some of the products are over? The answer is that while some products exceed takt time, others will be less than takt time. On average, you should be able to achieve your desired production rate. On any given day, your capacity will be determined by the product mix you are attempting to build. If the mix contains a higher percentage of the high work content products, compared to the mix you used to design the line, then you can’t expect to produce the same number of units without working overtime. From now on, you will not use the phrase “balance to the takt time”, but instead “balance to the time target”.

Balancing Workstations

<table>
<thead>
<tr>
<th>Workstation</th>
<th>Takt</th>
<th>Actual Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workstation 1</td>
<td>20 min</td>
<td>24 min</td>
</tr>
<tr>
<td>Workstation 2</td>
<td>20 min</td>
<td>18 min</td>
</tr>
<tr>
<td>Workstation 3</td>
<td>20 min</td>
<td>16 min</td>
</tr>
<tr>
<td>Workstation 4</td>
<td>20 min</td>
<td>24 min</td>
</tr>
</tbody>
</table>

Table 11.1

Work is not naturally balanced, and in order to achieve a smooth flow, with minimum queue time and inventory, it is usually necessary to make some adjustments. Your first pass at balancing four workstations might look something like the results shown above in Table 11.1. Your time target for this product is 20 minutes, but the initial distribution shows Workstation 1 and Workstation 4 over that target. If you do not change this balance, your best rate of production will be paced by the slowest station, Station 4 at 24 minutes, not the desired rate of 20 minutes. You are most concerned about the cases where you exceed the time target, since that will prevent you from achieving your production goals. You are also concerned when the work content at a station is significantly below the time target, since that will result in blockages and lowered productivity.

Let’s take a look at how you overcome these imbalances, with the goal of achieving a flow line that can meet the desired production rate of 20 minutes per unit. Remember that you are performing this analysis on a product-by-product basis. The six methods used to adjust work balance are:
The recommended starting point for balancing work, is by reducing or eliminating waste in the form of non-value-added (NVA) work steps. Not all of the work that is performed adds value to the product. Moving material from one place to another, for example, may be a task that must be done the way you are organized today, but that can be eliminated in the future, through an improved factory layout. Changing over a machine for the next production order must be done using today’s procedure, but can be reduced through the application of changeover reduction methods. These examples of non-value-added work steps become your first area of focus in attempting to balance work flow.

The reason for starting with this tool is simple: you can achieve multiple benefits by focusing on the elimination of non-value-added tasks. First, your objective of improving work balance can be accomplished by reducing the time spent on NVA tasks. Second, you are reducing product cost by removing work time from the product. Third, your manufacturing response time will be reduced by taking out processing time. Fourth, a reduction in cycle time is related directed to a reduction in work-in-process inventory. Finally, since more worker time will be spent on value-added work, productivity will go up. A focus on reduction of NVA work is too good an opportunity to overlook.

Do you always find opportunities to eliminate NVA tasks? No, of course not, but you certainly want to assess that opportunity first. You use your source document, the Standard Work Definition, which documents both value-added and non-value-added work steps, and points to the tasks that may be targets for elimination.

Finding waste, especially if you are just starting your Lean journey, should be fairly easy. While the traditional definition of waste is defined as “work that adds cost but doesn’t add value in the eyes of your customers”, you can paint with a broader brush to start. For line balancing purposes, the types of waste you look for, fall into two general categories:

1. Time spent preparing to do work. This is called setup or changeover time.
2. Time spent moving to and from the work, but not actually working.
Examples of the former are easy to identify in machine intensive environments, but even manual assembly lines often have a significant amount of changeover or setup time. Move time sometimes involves moving material, or sometimes it is simply unnecessary operator motion. Start with these two categories, and when you’re done, you will have undoubtedly uncovered a significant amount of waste.

Elimination of waste is not only a tool for line balancing. Every employee in the company should receive training on waste and waste elimination. Identifying opportunities for improvement across the company is the foundation of an employee suggestion system. The well-known Seven Wastes of the Toyota Production System can be used to help employees understand the concept of waste (muda in Japanese):

1. Overproduction
2. Waiting
3. Transportation
4. Inappropriate Processing
5. Unnecessary Inventory
6. Unnecessary Motion
7. Defects and Errors

Some of these wastes are obvious, while others are more subtle. Employees are often rewarded for overproducing, but from a Lean perspective this is considered a serious form of waste.

Relocating Work

The second balancing tool in your tool chest is a simple one: do a better job of balancing the work by moving tasks from one workstation to another. There are a variety of reasons why the original work balance was not satisfactory. Perhaps the work content times in your Standard Work Definition needed some adjustment, or maybe lack of balance only became apparent once the line was up and running. The Relocate Work technique involves transferring tasks from one workplace or worker to another, in order to better balance the flow.

Experienced Lean practitioners don’t jump too quickly to apply this technique in a new flow line. Some time should be allowed for the line to “settle down”, and for the learning curve effect to take place, before applying this balancing tool. Perfection is not to be expected, since human beings work at different speeds.
Moving work is most easily done for labor-based work steps. Taking work from John and giving it to Peter is a simple process, providing that Peter agrees! Machine-based work, however, is more challenging. To stop a machine and move a semi-completed product to the next machine doesn’t make much sense; typically you complete the required work on a single machine, before moving the product on. For this reason, you use the Relocating Work tool to balance labor tasks only.

As discussed above, in a mixed-model line, the work steps and times are unlikely to be the same for all products. Allocation of tasks needs to be done on a product-by-product basis. Balance issues can happen by product, and need to be addressed individually.

Adding Resources

A third balancing tool commonly used is adding additional resources, i.e. additional people, workstations or machines. Because there is a cost associated with additional resources, this balancing tool is not the first choice, but it may be necessary. It may be impossible to distribute assembly work evenly, and in order to avoid a bottleneck workstation, an additional station is added. An additional workstation occupies some floor space, and requires duplication of materials and tools.

A more subtle reason for adding resources is related to process variability. The initial resource calculations do not take into consideration the impact of variability in work time, or the impact of changeover time. The average or standard work time per unit may be 12 minutes, but in actuality, the time may vary between 10 and 14 minutes for the same product. Time variability can have a dramatic impact on product flow, and drive the need for additional resources. For this reason, static resource calculations, without considering process variability, can only be considered a first-pass. We will examine the use of simulation modeling tools in a future chapter, to analyze this type of balance challenge in a scientific way.

Adding In-Process Kanbans (IPKs)

The addition of inventory between machines or workstations is a powerful but often misunderstood technique. Actual work content time is usually variable and statistically distributed around a takt time. In other words, depending on the model being built, sometimes the work takes longer than takt, sometimes it is equal to takt and sometimes it is less than takt. Even for a single model, the time required to do the work usually has some inherent variability. Not everyone works at the same pace, and times can vary during the day. Workers may start out fresh in the morning, and be dragging by the end of the day. Although on average
the line can meet takt time, variability in the work time or between models can cause delays and bottlenecks. Adding some additional inventory can help smooth the flow of work, without having a significant negative impact on inventory or response time. This technique is called the addition of In-Process Kanbans or IPKs. If a resource is not able to meet takt time temporarily, adding additional pieces on both sides of the resource can help overcome delays and blockages for a limited amount of time. The number of takt time cycles that this inventory will cover depends on the number of pieces allowed between workstations. Although adding additional material violates the principal of single piece flow, it is often the best and least expensive solution to process variability, and to overcome time differences between models.

How many units or IPKs should be added? A common method to establish the number of IPKs is simply trial and error. Add additional pieces, starting with one, and monitor the throughput results. A more scientific method to analyze the impact of variability is to create a dynamic computer simulation model and conduct simulation experiments with different buffer quantities. The use of computer modeling assumes that the basic parameters of variability are understood, and can be modeled correctly. A focus on reducing process variability is an important key to a smooth flowing line. The number of pieces or units added using the IPK technique should be small, since the law of diminishing returns applies to the addition of inventory as a balancing tool.

New Lean practitioners often wonder when they will need to calculate the number of IPKs or pieces placed between machines or workstations, in order to smooth the work flow. The answer is: never! There is no formula to calculate the number of IPKs, unless there is a chronic imbalance of work content that exceeds the takt time of the line. If you could benefit from IPKs, this could be determined either by trial and error or by simulating the line performance using a computer simulation tool. As a rule of thumb, you will have few IPKs or sometimes none at all. Overcoming chronic imbalances, through the use of inventory, is the tool called Inventory Plus Time, discussed next.

Adding Inventory Plus Time

Another type of imbalance can occur, where the average work time exceeds the time target, and the resource will never be able to meet maximum demand. That resource or workstation is called a bottleneck. This chronic case, where the time target cannot be met, requires a different solution than the IPK method discussed previously. In addition to adding inventory to the line, it is necessary to have additional work time available, since the bottleneck resource cannot meet demand during the Effective Work Minutes. The strategy will be to build up
an inventory quantity by working additional time at the bottleneck resource, in
order to overcome this shortfall in production. During normal working hours,
the downstream internal customer can draw from this additional inventory, and
not wait. Additional work time must be available for this method to work. If
you’re already working three shifts, the resource of additional time is simply not
available, and this will not be a balancing option.

The formula for calculating the number of pieces that will be required to
overcome this type of imbalance is as follows:

\[
INV = (W \text{ MIN/TAKT}) - (W \text{ MIN/ST})
\]

where \(W \text{ MIN}\) are the work minutes available during the day, \(TAKT\) is the takt time
for the process, and \(ST\) is the standard time at the pacing resource, the bottleneck.

This calculated inventory quantity would be placed on both the upstream and
downstream side of the bottleneck resource. The upstream IPK quantity will be
used to supply the bottleneck resource during the time when the rest of the line
is not running, while the downstream IPK will ensure that the next downstream
workstation or machine is not starved for material during the normal work time.

This technique violates the single piece flow ideal, but it is often preferred
over buying a new piece of capital equipment. Evaluate the cost of the additional
inventory against the cost of an additional resource, and choose the lower cost
alternative.

Let’s create an example to illustrate the tool of using inventory and time to
overcome an imbalance at a machine. A machine cell with four linked machines
has a time target of 0.44 minutes per piece, but Machine 3 in the cell runs at 0.55
minutes per piece. Buying another machine is not an attractive option, so you use
some additional time, plus a calculated number of pieces before and after Machine
3 to overcome this imbalance. The formula you will use is:

\[
INV = (W \text{ MIN/TAKT}) - (W \text{ MIN/ST})
\]

The number of additional units is:
\[
INV = (420/.44) - (420/.55) = 955 - 764 = 191 \text{ units needed}
\]

The additional work time is:
\[
TIME = INV \times ST = 191 \times .55 = 105.05 \text{ additional minutes}
\]

Machine 3 needs to work an additional 105 minutes per day, and accumulate
191 pieces in order to overcome this imbalance. Stations 1, 2 and 4 work normal
working hours.
To address a true bottleneck resource, either the Time Plus Inventory or the Adding Resources techniques can be used. Should you buy another machine, add resources or add inventory plus time? Factors to consider include:

1. How big is the product, and do you have the space available? Extra inventory in the form of big green tractors between every workstation would be a challenge.

2. Do you have the additional time available? If you’re already running 3 shifts, you’re out of time.

3. What is the inventory worth? You would like to keep high dollar value material to a minimum.

4. How expensive is the machine? Do you already have one in-house? Can you supplement with a less expensive piece of equipment? In general, you calculate the cost of both alternatives, and choose the lower cost alternative. Brilliant!

**Sequencing**

In a mixed-model line, where more than one model is produced sequentially on the same line, there are differences in the work time or changeover time for various models, that have an impact on product flow, as we have discussed above. If the mix and order of production is not managed properly, portions of the line could become blocked or starved for material, overall capacity could be negatively impacted, and production goals could be missed.

A common reason for sequencing products in a particular order has to do with changeover time reduction. If you have a changeover between products, and those changeover times are always the same, then these times are not a sequencing factor. More often than not, there are differences in the changeover times, depending on which product you are going from and to. In the example shown in Table 11.3, you can reduce the overall changeover time by 2.4 hours by sequencing correctly rather than in first-in-first-out or random order.

Another reason why the Lean Manufacturers need to pay attention to the order in which products are built, has to do with differences in the work content times, as shown in Table 11.3. Conventional logic tells us that you should build all of the same products as a batch, together at the same time. If you need to build Product A, Product B and Product C today, you might be tempted to first build all of the As, then all of the Bs, and finally all of the Cs. If Product A requires more work that the average, you may find that the more you build, the more the line downstream
begins to “dry up”, since you are unable to keep up with the designed flow rate. Similarly, if you attempt to build Product C in a batch, and this product contains less work content than the takt time, you might find yourself blocked, since the downstream resource will not be consumed fast enough. Sequencing the products and alternating Product A, Product C and Product B can smooth out the flow and overcome these balancing challenges.

Creating Machine Cells

The term most commonly used when discussing the linking and balancing of machine work is *cellular manufacturing*. When you create a machine cell, you physically co-locate the equipment in the same physical area, set up the cell to run a specific part number, and run the parts one piece at a time. The improvements in quality, response time and productivity are huge. It is likely that two or more adjacent machines will not be balanced. This is to be expected since machines normally run at an optimum speed or cycle, that is not related to a calculated or desired time target. These imbalances, unless controlled, have the potential for generating large amounts of semi-processed product. The use of In-Process Kanbans helps control the flow of product between machines, keeping inventories of semi-finished product at formulated levels.

The linking together of adjacent machines, that are inherently imbalanced, may result in under utilization of capital equipment. For example, a machine with a cycle time of 60 seconds per piece will be able to produce approximately 400 pieces per shift. If a second machine, with a cycle time of 30 seconds per piece, is linked via In-Process Kanbans to the first machine, it will be required to slow down to run at the 60 second pace. Utilization at best for the second machine will be 50%. The temptation, especially if there is significant capital investment in the second machine, will be to share the second machine, in order to improve utilization, or to go back to batch and queue production methods. Management needs to weigh the cost of the inevitable additional inventory that results, against the capital investment costs incurred by under-utilizing equipment, and choose

<table>
<thead>
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<th>MODEL</th>
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<th>Process2</th>
<th>Process3</th>
<th>Process4</th>
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<td>3.5</td>
<td>5.3</td>
</tr>
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<td>C</td>
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<td>D</td>
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<td>10.5</td>
<td>3.4</td>
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</tr>
</tbody>
</table>

Table 11.2
the lower cost alternative. For this reason, Lean manufacturers in a machine-intensive environment prefer simpler, less-costly equipment, that can be physically linked and dedicated, without requiring additional inventory or excessive concern about utilization. While utilization is a consideration, it is a secondary rather than a primary performance metric in a Lean Manufacturing environment.

Overcoming Changeovers

Although linking resources directly, using the IPK method, is your preferred strategy for linking and balancing your flow line, it will be impossible to do so with long changeover times. While a machine is being changed over, it is not producing, and downstream customers will need consume an inventory of items already produced, either from a Material Kanban bin or from a FIFO lane. Furthermore it may be impossible to control the production sequence in order to optimize changeovers, and drive the number of changeovers to an impossibly high level. You may also have other uptime issues with machines, that would prevent you from linking them directly to the downstream customer. The signaling method of choice for overcoming changeovers will be the use of the Kanban Supermarket.

Instead of responding directly to an IPK signal or FIFO lane, your machine (or machine cell) will respond to a Kanban signal coming from a Kanban Supermarket. The quantity of an individual part will be calculated mathematically, in order to optimize the number of changeovers in a day against the amount of inventory stored in the supermarket. The consuming downstream process will pull parts from the supermarket, and not from the machine directly. Following is a step-by-step description of the methodology used to optimize the Kanban quantities and the number of daily changeovers. Refer to Table 11.4 below for an example of this interactive method, as you read through the steps.

**Step 1:** Calculate Average Changeover Time. The changeover times do not need to be identical, but you will need to calculate an average time using this method.

<table>
<thead>
<tr>
<th>MODEL</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
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<td>4.0</td>
<td>4.5</td>
<td>7.0</td>
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<td>1.9</td>
<td>5.5</td>
<td>.6</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 11.3
If you have widely different changeover times, depending on the “From-To” relationships, this method can still be used but you will need to first optimize the sequence of changeovers using the “Rhythm Wheel” approach (Google it!). In this example the Average Changeover Time is 60 minutes.

**Step 2:** Establish Effective Work Minutes Per Day. This topic has been covered in a previous chapter. Remember that the Effective Work Minutes for a machine may be different from labor-related processes, since a machine doesn’t need to take a break or eat lunch. The Effective Work Minutes in this example are 870, over two shifts.

**Step 3:** Calculate Total Run Time Required. Refer to Table 11.4B for this calculation. Multiply the Daily Volume for each part number to be run by the Run Time for each piece. Sum this result to calculate the total daily machine run time required to meet customer demand. In this example you need 534.34 minutes of pure run time on the machine.

**Step 4:** Calculate the Changeover Time Available. Once you know the Effective Work Time and the Total Run Time, you can calculate the time left over for changeovers by subtracting one from the other. In this example you have 335.66 minutes of time remaining in the working day to do changeovers.

**Step 5:** Calculate the Number of Changeovers Possible. Divide the Changeover Time Available by the Average Changeover Time. In this example, you can do 5.59 changeovers per day. This is the number that you will meet, by adjusting the batch sizes of the various parts, through in iterative analysis.

<table>
<thead>
<tr>
<th>Table 11.4A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Changeover Time</td>
</tr>
<tr>
<td>Effective Work Minutes Per Day</td>
</tr>
<tr>
<td>Total Run Time Required</td>
</tr>
<tr>
<td>Changeover Time Available</td>
</tr>
<tr>
<td>Number of Changeovers Possible</td>
</tr>
</tbody>
</table>

**Step 6:** Adjust the Daily Changeovers. Refer to Table 11.4B below for this next step. Start this analysis by attempting to run every part every day, with a batch size of one day for each item. Replace the “Daily Changeovers” value to 1.0 for every item. Since there are 12 parts that need to be run, this will require 12 changeovers, which exceeds your goal of 5.59 or less. Begin to reduce the number of daily changeovers by adjusting the “Daily Changeovers” values. For example, a value of 0.1 means that you would perform a changeover every 10 days, and that the batch quantity for that item would be a 10 day supply. Logically you should...
try to reduce the number of changeovers for low-volume items first, and run the high-volume items more often. Your overall goal is to achieve the goal of 5.59 changeovers per day or less, while at the same time minimizing your inventory investment. You may also need to take into consideration the cost of the various item in your analysis, and optimize based on total dollar value as well as simple quantities. In this example you have achieved 5.4 changeovers per day with the mix of changeovers shown.

### Table 11.4B

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Daily Volume</th>
<th>Run Time</th>
<th>Total Run Time (Min)</th>
<th>Daily Changeovers</th>
<th>Batch Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>80303-R</td>
<td>DR12 Right Side Housing</td>
<td>56.00</td>
<td>0.65</td>
<td>36.4</td>
<td>0.5</td>
<td>112</td>
</tr>
<tr>
<td>80303-L</td>
<td>DR12 Left Side Housing</td>
<td>56.00</td>
<td>0.65</td>
<td>36.4</td>
<td>0.5</td>
<td>112</td>
</tr>
<tr>
<td>80525-R</td>
<td>DR54 Right Side Housing</td>
<td>84.00</td>
<td>0.65</td>
<td>54.6</td>
<td>0.5</td>
<td>168</td>
</tr>
<tr>
<td>80525-L</td>
<td>DR54 Left Side Housing</td>
<td>84.00</td>
<td>0.65</td>
<td>54.6</td>
<td>0.5</td>
<td>168</td>
</tr>
<tr>
<td>80696-R</td>
<td>DR11 Right Side Housing</td>
<td>65.00</td>
<td>0.65</td>
<td>42.25</td>
<td>1</td>
<td>65</td>
</tr>
<tr>
<td>80696-L</td>
<td>DR11 Left Side Housing</td>
<td>65.00</td>
<td>0.65</td>
<td>42.25</td>
<td>1</td>
<td>65</td>
</tr>
<tr>
<td>89210-R</td>
<td>SD04 Right Side Housing</td>
<td>3.20</td>
<td>1.10</td>
<td>3.52</td>
<td>0.1</td>
<td>32</td>
</tr>
<tr>
<td>89210-L</td>
<td>SD04 Left Side Housing</td>
<td>3.20</td>
<td>1.10</td>
<td>3.52</td>
<td>0.1</td>
<td>32</td>
</tr>
<tr>
<td>81813-R</td>
<td>OS31 Right Side Housing</td>
<td>76.00</td>
<td>1.60</td>
<td>121.6</td>
<td>0.5</td>
<td>152</td>
</tr>
<tr>
<td>81813-L</td>
<td>OS31 Left Side Housing</td>
<td>76.00</td>
<td>1.60</td>
<td>121.6</td>
<td>0.5</td>
<td>152</td>
</tr>
<tr>
<td>87654-R</td>
<td>OS01 Right Side Housing</td>
<td>8.00</td>
<td>1.10</td>
<td>8.8</td>
<td>0.1</td>
<td>80</td>
</tr>
<tr>
<td>87654-L</td>
<td>OS01 Left Side Housing</td>
<td>8.00</td>
<td>1.10</td>
<td>8.8</td>
<td>0.1</td>
<td>80</td>
</tr>
</tbody>
</table>

534.34  5.4

**Step 7:** Establish Bin Sizes. The parts being produced may be of different sizes and weights, and your next step is to establish a desired bin (container) size for each item, along with the number of pieces that will fit in each bin. Ergonomics and weight considerations are important, and there are OSHA requirements covering maximum container weight. The column labeled “Bin Size” in Table 11.4C shows the number of pieces allowed per bin.

**Step 8:** Calculate the Number of Replenishment Bins. Divide the Batch Size by the Bin Size, and round up. This is the number of empty bins that you will need to accumulate before you would changeover and run that part. To do otherwise will increase the number of changeovers that you do, and reduce your available run time on the machine.

**Step 9:** Calculate the Total Number of Supermarket Bins. If you only had the number of Replenishment Bins, as calculated above, the supermarket would be totally empty while the bins were being refilled. To avoid this you will need some additional containers of material in the supermarket. In this example, shown below in the column labeled “Total Bins”, we have used a simple “Two-Bin Kanban” approach and doubled the number of bins calculated. Keep in mind that you may be able to get by with a fewer number of secondary bins, if the supplying machine
can changeover and run the parts in less time than allowed. Reducing the number of secondary bins is a great way to reduce the total supermarket inventory, if possible.

**Table 11.4C**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Batch Size</th>
<th>Bin Size</th>
<th>Number of Bins</th>
<th>Total Bins</th>
</tr>
</thead>
<tbody>
<tr>
<td>80303-R</td>
<td>DR12 Right Side Housing</td>
<td>112</td>
<td>40</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>80303-L</td>
<td>DR12 Left Side Housing</td>
<td>112</td>
<td>40</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>80525-R</td>
<td>DR54 Right Side Housing</td>
<td>168</td>
<td>40</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>80525-L</td>
<td>DR54 Left Side Housing</td>
<td>168</td>
<td>40</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>80696-R</td>
<td>DR11 Right Side Housing</td>
<td>65</td>
<td>40</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>80696-L</td>
<td>DR11 Left Side Housing</td>
<td>65</td>
<td>40</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>89210-R</td>
<td>SD04 Right Side Housing</td>
<td>32</td>
<td>40</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>89210-L</td>
<td>SD04 Left Side Housing</td>
<td>32</td>
<td>40</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>81813-R</td>
<td>OS31 Right Side Housing</td>
<td>152</td>
<td>40</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>81813-L</td>
<td>OS31 Left Side Housing</td>
<td>152</td>
<td>40</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>87654-R</td>
<td>OS01 Right Side Housing</td>
<td>80</td>
<td>40</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>87654-L</td>
<td>OS01 Left Side Housing</td>
<td>80</td>
<td>40</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Since you will be accumulating Kanban cards or bins before you are authorized to changeover and run a batch of parts, you will need a way to track this information. A simple technique is to set of a visual Kanban Production Board, where the information can be displayed and tracked.

**The Self-Balancing Line**

In spite of all your best efforts, work done by human beings is inherently variable. You can reduce this variability by implementing Standard Work; this is an essential element of your Lean strategy. Another Lean method to smooth the work flow is sequencing, as discussed earlier in this chapter. A tight product family definition helps ensure that the work content of different products is within a recommended range. Perfect balance, however, remains elusive and the result will be lower throughput and lower productivity.

A creative technique to overcome inherent imbalances is the Self Balancing Line. Delays and blockages caused by work content differences and human factors are greatly reduced by under-staffing the line and having workers move to where the work needs to be done, usually within a zone around their primary workstation. Instead of being glued to a single workstation, the operator would work at the upstream and downstream positions as well, as dictated by the work flow. If there’s nothing to work on, move up. If the downstream position is blocked, move down. In order for the Self Balancing Line method to work properly, the following elements need to be in place:
1. Standard Work Definition has been created for every workstation.
2. The work is performed sequentially.
3. The line layout is reasonably compact, to reduce move time.
4. Hand-offs from one worker to another need to be “clean”.
5. Operators are cross-trained and certified for at least three consecutive workstations.
6. Operators need to be willing to move.
7. Operators are willing to work as a team.
8. Operators are able to work while standing. Working while sitting makes it more difficult to move in the line, especially if the takt time is short.

Table 11.5 shows in more detail how this technique actually works. Operators have an IPK visual signal on both the upstream and downstream side of their primary workstation. The rules for either staying, moving up, or moving down are shown below. By FULL, we mean there is a completed unit at that position, and the action is an answer to the question “What do I do next?”

The benefits of the Self Balancing Line can be substantial. Productivity gains of 30% or more have been reported, and daily throughput takes a similar jump upwards. While the work flow still needs to be balanced, the effect of variation in work time is greatly reduced.

<table>
<thead>
<tr>
<th>UPSTREAM</th>
<th>WORKSTATION</th>
<th>DOWNSTREAM</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMPTY</td>
<td>FULL</td>
<td>FULL</td>
<td>MOVE UP</td>
</tr>
<tr>
<td>EMPTY</td>
<td>EMPTY</td>
<td>FULL</td>
<td>MOVE UP</td>
</tr>
<tr>
<td>FULL</td>
<td>FULL</td>
<td>EMPTY</td>
<td>STAY AND WORK</td>
</tr>
<tr>
<td>FULL</td>
<td>FULL</td>
<td>FULL</td>
<td>MOVE DOWN</td>
</tr>
<tr>
<td>FULL</td>
<td>EMPTY</td>
<td>FULL</td>
<td>STAY AND WORK</td>
</tr>
<tr>
<td>FULL</td>
<td>EMPTY</td>
<td>EMPTY</td>
<td>STAY AND WORK</td>
</tr>
<tr>
<td>EMPTY</td>
<td>EMPTY</td>
<td>EMPTY</td>
<td>MOVE UP</td>
</tr>
<tr>
<td>EMPTY</td>
<td>FULL</td>
<td>EMPTY</td>
<td>MOVE UP</td>
</tr>
</tbody>
</table>

Table 11.5

Balancing With Options

It is common in many industries to offer a wide variety of product options. Tractor buyers, for example, can select literally hundreds of optional features and tools when placing their order. We won’t question the wisdom of offering so many choices, but many of them are very low volume. Instead we offer suggestions
on how to deal with them on the flow line. The main challenge of installing options is the additional work content that is added, along with the additional process variability. Productivity and throughput of the line suffers when a high work content model is introduced, as the line starts to dry up downstream from the unit, and is blocked upstream from it. Workers will be waiting, and even if they are willing to help (flex), it is often difficult or impossible to add additional workers to a bottleneck station. While this situation will never be ideal, here are some suggestions for overcoming this challenge.

**Move Option Work Into Feeder Lines.** Move as much optional work as possible into feeder lines, off of the final assembly line. By achieving a consistent flow and reduced variability on the main line, the output of final product will be much more consistent. Variation in work content can be managed more easily in feeder lines by adding FIFO lanes, additional workstations, and having operators move within a work cell. The subassembly itself may be smaller, which is also very helpful.

**Add Overflow Workstations.** This strategy is identical to the “Add Resources” balancing tool discussed earlier. What you are doing is oversizing the line to support potential demand from required options. You need to combine this method with operator movement (flexing), and with variable staffing. Put the right number of people on the line to complete the work that needs to be done today, and with additional workstations and operator movement, you will be able to maintain a target flow rate. You do not want to staff every workstation, but have a workplace available when needed.

**Sequence Product Mix Strictly.** A failure to create robust sequencing rules will have a negative effect on productivity and throughput, and this need becomes especially critical if you are dealing with a large number of options. Production control needs to produce a daily production plan that includes the optimum mix and sequence, and operators need to follow that sequence.

**Add Additional IPKs.** If some workstations are impacted by options and occasional higher work content, you may be able to overcome this with some additional IPKs on the upstream and downstream side. This strategy assumes that time lost when a high option product arrives at the station can be regained by building one or more low option products immediately thereafter. The IPK option will not work if the production sequence has not been optimized.

**Promote Operator Movement.** Underlying several of the methods mentioned above is the need to have workers move to the work as needed.
Balancing Work With POLCA

There are many examples of companies who look at the techniques of family definition, takt time, single piece flow and line balancing and say “This won’t work for us!”. The types of industries that typically have a harder time flowing work include:

- Job Shops with many different routings.
- Machine intensive environments.
- Aerospace and Defense, with many different products.
- High Mix, Low Volume environments.

There are regulatory requirements that may require you to build products in batches, in order to maintain traceability of materials and labor. A large number of different products also creates training challenges, where switching from one product to another requires some learning or relearning.

An innovative technique documented in the book *Quick Response Manufacturing* by Rajan Suri is called *Paired Overlapping Loops of Cards with Authorization* (POLCA). This technique is used in cases where a progressive flow line would be difficult to create, due to the large number of possible routings or process flows. In these environments resources must be shared, but you want to avoid overloading any one resource with too much work, as that leads directly to long queue times, excessive WIP and slow response. The POLCA technique calculates a number of authorization cards, based on volume and process lead-time, for each possible pair of resources. In order for a job to be started, for a job that travels from Resource A to Resource B, a card showing that relationship must be available. If no such cards are available, it signifies that the loop is “full” and no new jobs for that loop can be started until a card is freed up. A card becomes free when the job is completed through the second resource.

The overall effect of the POLCA system is to smooth the workload across multiple independent resources, improving throughput time and reducing WIP inventory. Other related benefits include improved productivity, reduced floor space needs and improved quality. While the preferred process design method continues to be the flow line, as covered in this book, the POLCA method can be a powerful hybrid system for high-mix low-volume production environments.

Lessons Learned

Before finishing your line design, it is important to evaluate the line from the perspective of balance. Without good balance, throughput and productivity will suffer.
Our tool kit includes six balancing tools: eliminate waste, relocate work, add resources, add IPKs, add inventory and time, and sequencing.

Eliminating waste is a great first choice balancing tool, since it includes multiple benefits.

Implementing the Self Balancing Line philosophy goes a long way to overcoming inherent variability, and improving productivity and throughput.

The techniques of takt, flow lines and tight product families won’t work in all cases. An alternative for balancing work in a high mix low volume production environment is the POLCA method.
You are close to understanding your final factory design, and are now ready to create a preliminary picture of your proposed flow environment, by arranging the calculated resources into a block diagram. The preliminary line design should look like your original Mixed Model Process Flow Diagram, but with three important differences:

1. The preliminary line layout is done at the detailed resource level, instead of the process level. On your PFDs you may have a process called Assembly, but on the preliminary line layout you will place nine individual assembly workstations, based on your resource calculation of nine Assembly labor resources.

2. You need to arrange all of the processes logically and in close proximity, even though not all products may require all processes. You optimize the layout for the highest volume.

3. The preliminary line layout will display the signaling methods to be used to connect one process to another, and one workstation to another. Decisions need to be made regarding these pull signals.

The goal in the preliminary line layout is to connect all of the various resources, workstations and machines, in order to achieve a connected pull system. The ability
to build products one at a time in a flow process, is key to many of the benefits of Lean Manufacturing: fastest response time through the plant, minimum WIP inventory, quick feedback on quality issues, reduced floor space and improved productivity. Although it may not always be possible, getting to single piece flow is an important objective.

Connecting Processes

There are a variety of tools that you can employ as signals in the line, to pull work from one process to another, and from one workstation to another. The right tool depends on the characteristics of the work, of the physical product, the difficulty of management, the physical space, and the company culture. Part of the skill-set of an experienced Lean designer is to be able to select the right tool for the job.

The central objective of a pull signal is to trigger the movement of material, or the doing of work, based on a formal signal, and based on need or actual consumption. This is in contrast to a push method, which signals material movement or work based on a schedule or predefined plan, whether or not the material or work is needed at that time. When you create your preliminary line layout, one of the non-negotiable goals is to create pull signals for all material and work, without exception. As you will see, the exact tool depends on the circumstances. There are five main pull methods that you will use.

Tool 1: Direct Connect

The direct connect method means that there is no inventory allowed between two processes, or between two workstations. Only one piece is allowed at the upstream workstation, and only one at the downstream workstation, as shown in the illustration in Figure 12.1. The piece at Workstation One cannot be moved until Workstation Two is available. The signal is the empty downstream workstation.

This method results in the least possible WIP inventory, and the least possible floor space. Lean purists might prefer this method, since it appears to be the least
wasteful, and most direct. There are some serious challenges with this approach, however:

1. If a piece cannot move until the next downstream piece has also moved, the entire line needs to advance like a train. If there is no variability in the work time, and every piece always takes exactly the same work time, then there would be no delay. In a mixed model line, however, we expect that the work content times will vary. The line needs to wait until the slowest workstation has finished, before it could advance. This will cause productivity to drop like a rock.

2. Without any formal pull signal, other than an empty workstation, operators will have a strong tendency to “break the rules” and build up inventory. They do this so that they can keep working, which is good, but our goal of single-piece flow will be lost, and WIP will accumulate.

For these reasons, the direct-connection method is not generally recommended, but there are exceptions where this method is either necessary or acceptable.

A Large Product. Adding addition units between workstations or between processes if the product is large will consume floorspace, and may simply be out of the question. Attempting to put a large combine between every combine assembly station will double the length of the line. How large is large? If adding a unit between workstations will significantly increase the length of the production line, the direct-connect signal method may be necessary.

A Long Takt Time. We acknowledged above that if there is no “buffer” between workstations, the amount of blockage and waiting will increase, in turn lowering throughput and productivity. The more time that an operator has to complete the work, the easier it is to recover lost time, to help coworkers, and maintain the desired flow rate. If the takt time is long enough, additional buffer inventory may not be necessary, even if the product is not large. How long is long? This is a value judgment, but our rule of thumb is that takt times over one hour do not require additional buffer inventory, and can use the direct connect method. On the other hand, the shorter the takt time, the more additional buffer is needed.

In summary, unless you are confronted with a large product, or are dealing with a long takt time, we do not recommend the direct connect method. The reason for this will be more clear when we examine the other four pull signal options.

Tool 2: In-Process Kanbans

The word Kanban means signal in Japanese, and Tool 2 is a unique pull signal, called an In Process Kanban or IPK. An IPK is an empty space between two
workstations, where one additional unit is allowed. An operator completes a piece at Workstation One, and places the piece in the empty downstream IPK. Unlike the Direct Connection method discussed in Tool 1, the operator at Workstation One does not need to wait for Workstation Two to be available or open. If the downstream IPK is open or empty, fill it. Workstation One can continue working, and start and finish another piece. The IPK does not allow unlimited WIP inventory, of course. If Operator One finishes a second piece, and the downstream IPK is still occupied, he will leave the second piece at the workstation, and stop working at that station.

Of course, if the operator at Workstation One simply stops working, and waits for the IPK to clear out, productivity suffers. Instead the operator should move in the direction of the blockage, downstream, and work somewhere else. This “somewhere else” is not a random location. The zone in which an operator could work is carefully planned ahead of time, and the operator is certified in the work done at all workstations in the defined zone. The IPK provides one additional Takt of time before the operator would be required to move.

Let’s examine the use of the IPK from the perspective of Workstation Two. If the operator at Workstation Two has an empty workstation, and is ready to work on the next unit, it is pulled from the upstream IPK. In a well balanced line, units will go into the IPK and be pulled from it continually; the units do not sit in the IPK for an entire Takt time cycle. If there is a delay upstream, however, Workstation Two may reach for the unit in the upstream IPK and find it empty. Although Workstation Two is available to do work, there is nothing to work on. The operator would then be required to move, but this time upstream instead of downstream.

Allowing an extra piece in an IPK helps overcome normal variability that occurs in a mixed model line, or even in a dedicated line with only one product. Time that might be wasted through blockage or waiting can be recovered by allowing the operators to keep working, at least one more Takt time cycle. The
IPK is not a panacea for a poorly balanced line, but since variability is inherent if human beings are doing the work, the addition of an IPK is highly recommended, even if you feel that the line is “perfectly balanced”.

A common question from line designers is, “How do we calculate the number of IPKs needed between two workstations?” The answer is: you can’t, there is no formula for the number of IPKs, if the variability of work time is normally distributed, i.e. sometimes faster and sometimes slower. The best we can recommend is to model the line performance using computer simulation, and make reasonable assumptions regarding the expected level of variability. The Law of Diminishing Returns for IPKs kicks in very quickly, so when in doubt, just add one IPK (one piece) between workstations as a default. You will see in the next tool, cases where more than one piece is beneficial.

**Dedicated IPKs.** The IPK has no part number identity. Whatever unit is next in the production sequence will go in and out of the IPK. In some cases, it may be desirable to assign an IPK to a specific part number, if the number of different units going through a process is small. For example, if a process produces three different models, you could give each model its own IPK, assuming that you have the physical space to do so. The downstream customer would simply pick the unit needed from the appropriate IPK. This in turn provides a signal to the upstream process, to produce another one. The advantage of this method is that it eliminates the need to manage the upstream process, with a production sequence or schedule. They can simply build what was used, using the dedicated IPKs as a signal.

This method runs out of steam fairly quickly, as the number of different models increases. The signaling becomes more complicated, and the amount of space needed grows. If a single IPK is used, the supplying process needs a production sequence, or dispatch list, to build to, that is synchronized with the production plan for the downstream process.

**Tool 3: FIFO Lanes**

There is not much difference between an IPK and a FIFO Lane, but we are using the term IPK to refer to a single piece or a single product. A FIFO lane is an IPK that allows *more than one piece*, and is also structured to maintain a First-In-First-Out sequence. A good example of a FIFO lane can be seen at a McDonald’s Restaurant, when a chute is used to store a certain number of the best selling items. The Big Mac chute will hold more than one burger, but there is a limit to the number of burgers that will fit. There are many cases where more than one piece between processes or workstations is desirable and even necessary. Let’s look at some examples, and the reasons for needing a FIFO Lane.
**Short Takt Time.** If your Takt time is less than one minute, one piece between each workstation may not be enough to overcome time variability. Just saying hello to your co-worker could cause you to miss a Takt time or two, and it will be hard to make up that shortfall by speeding up. There is no formula to tell you the right number of pieces, but the shorter the Takt time and the more the variability, the more it will be advisable to add additional pieces between workstations in the form of a FIFO lane.

**Changeovers.** If the upstream workstation or process experiences changeovers between products, when the process is preparing to work but not actually working, it will be necessary to overcome this delay with additional inventory. Creating a FIFO lane with the correct number of pieces to keep the downstream workstation supplied, while the upstream workstation is being changed over, is the lowest inventory solution. Two other options are discussed below, Kanban Direct and Kanban Supermarket.

The number of pieces needed in the FIFO lane can be estimated by dividing the maximum changeover time by the Takt time of the consuming workstation:

\[
\text{Max Changeover Time / Takt of Consuming Resource}
\]

**Optionality.** If an optional process is sized at less than 100% of the consuming process volume, the use of the FIFO lane technique can help with challenges in supply. If an optional process is not required 100% of the time, but it is difficult or impossible to control exactly when it is needed in the consuming process (inability to sequence the option), it is likely that the optional process will be a bottleneck unless countermeasures are taken. A simple countermeasure would be to increase the number of pieces available to the consuming process, in the form of a FIFO lane. In that way if several items in a row require the option, additional inventory will be available. The number of pieces needed in the FIFO lane will be a function of the production rate of the supplying process, plus the number of units that may be consumed in a sequence.
**Quantity Consumed.** The FIFO lane can be used if more than one unit from a supplying process or workstation is needed at the same time. A wheel line will be designed to produce five wheels, including a spare, in the time that it takes to build one car chassis. When the wheels are installed, all five will be needed at more or less the same time. A FIFO lane sized for five wheels is a simple way to handle that need, and the space for five wheels needs to be available.

**Batch Processes.** There may be supplying processes that produce in batches, i.e. more than one piece arrives at the same time. The FIFO lane will allow space for these additional units, and also control the risk of overproduction, by providing a visual signal to the upstream process when the FIFO lane is full.

**Tool 4: Kanban Direct**

So far we have discussed pull signals that involve a few number of pieces, or none at all, between workstations, based on FIFO logic. There are conditions where this method won’t work, or when you want to opt for a simpler pull signal solution:

*Long distance between the two processes.* A long distance between the two workstations or processes makes it hard to use the IPK/FIFO Lane signaling method. Moving the product one piece at a time, one move per Takt time, might generate a huge amount of non-value-added move time. It will be necessary to combine the units into an efficient quantity before they are moved.

*The IPK or FIFO Lane can’t be seen.* The IPK and FIFO Lane methods are visual signals that, as the term implies, requires that the upstream workstation be able to physically see them. If they are not visible, they won’t work. You could imagine a video camera showing a hard-so-see location, but that might be a stretch.

*Dangerous or Restricted Access Processes.* There may be cases when the access to a downstream workstation is restricted. Opening and closing a clean-room every Takt time to fill an IPK is not a good choice if the cycle is short, or if temperatures need to be constant.

*Batch Processes.* As we discussed in Tool 3, if the supplying process builds in batches, it may be necessary to use another signaling method to downstream internal customers.

*Low Volume Processes.* If a supplying process is optional and low volume, it may be much more efficient to produce in reasonable quantities instead of trying to respond to usage on a piece-by-piece basis. An operator will be
able to move to the optional process to fill a bin of parts, if this is required a few times a day, as opposed to constantly trying to keep up with usage on an as-needed basis.

![Diagram of Kanban Direct method](image)

The Kanban Direct method, Tool 4, will be created like this:

1. Set up two quantities of an item, with enough inventory to last a reasonable period of time. The actual quantity is calculated based on the usage of the item, and how often you want to move it from the supplying process to the consuming process. The smaller the quantity, the more frequent the moves.

2. Consume from one quantity (bin) at a time.

3. When the bin is empty, deliver it (or a proxy in the form of a card or other signal) to the upstream process to be refilled. While it is being refilled, consume from the second container.

4. When the upstream process fills the bin with the designated quantity, deliver it to the consuming process directly.

This is the standard Kanban methodology that you may be familiar with already. The reason that this method is called *Kanban Direct* is that there is not intermediate inventory between the supplying process and the consuming process. The Kanban bins are delivered directly to the consuming process. This is only recommended if the supplying process is dedicated to the consuming process, and does not do work for anyone else. The producing process should be available to work on and fill an empty bin when it arrives. A shared resource, which we will discuss next, may or may not be available, and you run the risk of depleting both Kanban bins and stopping the line when you run out of parts.
Tool 5: Kanban Supermarket

The final pull signal is similar to Tool 4, in that you use the Kanban bin method instead of an IPK or FIFO lane. The Kanban Supermarket is needed when the upstream process is shared, and is an internal supplier to more than one area of the plant. This is extremely common in machine-intensive environments, where expensive equipment is shared as much as possible.

Although there needs to be sufficient capacity overall to supply all of the various demands on this process, you can’t be guaranteed at any given time that the process will be available. Trying to supply the downstream process directly, as you did with Tool 4, will be too risky. In this method, you add additional inventory using the Kanban method, and store it in a “supermarket”. The Kanban Supermarket is an inventory location located conveniently close to the line, with an additional quantity of the same material. The Kanban bins in the downstream process will be filled from the supermarket. As the bins in the supermarket are depleted, they will be filled by the upstream process.

![Figure 12.5](image)

The use of a Kanban Supermarket does add more inventory to the system, but this is preferable to taking the risk of stopping the line due to parts shortages. Over time, the supermarket quantities can be reduced, once experience in usage and the Kanban method have been gained.

The difficulty in connecting shared resources, and hence the difficulty of achieving single piece flow, is one reason why flow manufacturers prefer smaller, simpler and less expensive machines that can be physically connected, even if the machine utilization is lower. The strong incentive with an expensive piece of equipment, is to run it as much as possible, sharing it if possible. This leads to the waste of over-production, by keeping the machine working, by building inventory that is not needed in the short-term. Expensive machines promote an excessive management focus on machine utilization. Machine utilization can’t be ignored,
but your goal is to produce what is needed, when it is needed, not to produce material in order to keep people busy or machines running to “earn hours”.

Using your Mixed-Model PFD, along with your resource calculations, you are ready to create a preliminary line layout. We call this a preliminary or conceptual line layout, because you are not yet ready to commit to a final, dimensionally correct CAD-level drawing. You are interested in knowing how the products flow from workstation to workstation, whether you organize the work in parallel or sequentially, and where you need to use the supermarket technique to connect processes. The way in which you organize the flow of work has a big impact on throughput and quality. Try to organize work sequentially, in order to allow multiple operators to perform quality checks, following the “check-do-check” methodology. Too many sequential workstations add more opportunities for imbalances, and have a negative impact on both productivity and throughput.

**Workstation Definition**

It is not enough to know that you need a certain number of assembly workstations or machines for a specific process. You must also assign specific work steps to each workstation, in a step called Workstation Definition. You have already documented the detailed work steps, as part of your Standard Work Definitions, including the tasks that may have an increased quality risk due to process variability. You will now allocate the work among the number of calculated workstations within each process. This step applies mainly to labor resources. It doesn’t make sense to stop a machine in the middle of a processing cycle, and then transfer the material to a second machine of the same type, to continue on with the same work. Human beings are more flexible, and can perform many different tasks. Allocating labor work into sequential workstations is possible, common and recommended, whereas machines will usually be organized to work in parallel. Once started, the work will be completed on the same machine.

There are several reasons why we choose to organize labor work sequentially rather than in parallel:

- By organizing the work sequentially, it is only necessary to present the required materials to one workstation, where it is consumed. Working in parallel, the same material needs to be replicated across a number of workstations.
- Operator learning curve at a workstation can be reduced significantly, if the operator is only required to learn a portion of the work. For example, two hours of work, divided among six workers, reduces the amount of work to be mastered, to twenty minutes of work per operator, at least to start with.
• By dividing the work sequentially among a number of different operators, each piece is worked on by more than one person. This is extremely beneficial for the detection of defects and errors, and for the implementation of the Check-Do-Check method. Each work step, subject to quality risk or variability, is checked by at least two operators before being allowed to continue down the line.

If the work content in a process has been recorded on the Standard Work Definition in sufficient detail, the formal step of defining and balancing the work to individual workstations is relatively easy. It is not as simple as dividing the work equally by the number of workstations. The following items need to be considered when creating workstation definition:

1. The workstation definition in a mixed-model line must be done product by product, since the work content and time can be different. Start by dividing the total work content equally by the number of workstations. This gives you a time target to group the work to, for a specific product. This time target may be equal to, less than, or greater than the takt time for the process, depending on the work time for the model in question. The time target should not be significantly different from takt time, unless you have a wide range of work content times in the family.

2. Do the work steps included at the workstation make sense? It may be physically impossible to break the work sequence between certain tasks, or impossible to move the material. Fixtures or tooling may be required for certain steps that cannot be moved.

3. Are the operator skills logical and consistent at the workstation? It would not make sense to include work steps that are performed by a different labor category.

4. Is there physical space for the material that will be consumed? Space limitations will influence the work steps that can be performed at a workstation.

Where work is divided into sequential groupings, Workstation Definition is a highly important implementation step. After all, you are defining the exact work to be performed at a workstation. Input from the operators is highly useful and recommended. Otherwise, you may find yourself going back to the drawing table at a later date!
Preliminary Line Layout

Figure 12.6
Preliminary Layout Notes

1. The processes of Final Assembly, Test and Pack are the processes that anchor this line, so we start with these.

2. Final Assembly and Pack work is divisible into sequential workstations.

3. The work in the Test process is not divisible, and the entire test needs to be completed on the same machine. Test workstations/machines are therefore organized in parallel.

4. The Motor process is linked to the Final Assembly process via a Kanban Supermarket. This was done primarily for ease of management.

5. The Mold process involves substantial changeover time, and will be impossible to connect to Final Assembly directly. It is also connected via a Kanban Supermarket.

6. We placed IPKs. More about these in the chapter on Balancing.

Is it always possible to connect all processes directly? Although this is the ideal, the answer is no. Any time that a resource is shared it will be more difficult, although not impossible, to connect the resource directly to a downstream consuming process. It will also be difficult to physically link machines with lengthy changeover times. While the machine is being changed over, it is not producing, and you need some inventory available to supply the downstream processes, while the changeover is taking place. You may have processes that cannot be connected for other reasons: clean rooms, dangerous equipment or processes, or special environmental or physical requirements. You may even have monuments: large pieces of equipment that are too big to move, or damaged if you tried to do so. Paint booths, in many plants, are monuments, and even if they’re not well located, they are difficult and expensive to move, and usually stay where they are.

The method you will use to connect these independent processes, that cannot be directly connected, is called a Kanban Supermarket. The supermarket is an intermediate inventory location adjacent to the consuming line, that allows a connection and pull signal to the upstream independent resource, to refill the supermarket quantity of material. While single piece flow is not achieved between independent processes, when using Kanban supermarkets, they do have the benefit of eliminating the need for scheduling the upstream resource, by providing a Kanban pull signal. The Kanban supermarket also puts strict limits on the amount of inventory that can be produced and stored.
Figure 12.6 is an example of a preliminary line layout for your power tool factory.

The CAD Layout

There is no right way to accomplish the objective of completing a CAD drawing of the new line. Some people like the paper cutouts on a blueprint of the factory layout. Some people, with skills most of us lack, put together physical scale models. Our favorite method is an interactive session between the implementation team and a patient CAD operator. A CAD-enabled computer is connected to an LCD projector that displays the floor layout on a screen. You need access to the preliminary conceptual layout, as reference.

Start with the processes that anchor the line, the processes that consume the outputs of other processes. We refer to them as “Main Line” processes, the ones with the highest throughput volume. Proceed process by process, until you have accounted for all the processes on your process list.

You may remember the sign “Open Duck Season” in a Bugs Bunny cartoon, followed immediately by dozens of shotguns firing at Daffy Duck. “Open Season on Line Design” is a meeting where you invite people to come up with scenarios that can challenge or “break” your line design. This is not a time for playing “devils advocate”. This is an opportunity to provide the implementation team with constructive criticism, make them aware of past nightmares, and to see how the line design measures up to those challenging circumstances. Examples could be, unexpected volume due to a new customer, a complicated order mix or a natural disaster. “Remember that time we got hit with a month of orders in three days when hurricane Catherine hit Tampa?”. How would you deal with that? The implementation team has to be able to answer.

Beyond the Layout

The details of a line implementation project are many, and could occupy an entire new book. A large part of the total effort is spent dealing with fixture design, outside contractors and suppliers, designing material delivery equipment, and training operators in the new way of life. Think of the effort required to build a new house. The work has only just begun when you receive a set of working drawings from your architect. A failure to design your new house well will have a dramatic effect on your building schedule and cost, and the same analogy applies to your new production line design. In the following chapters, before you call the design done, we will discuss how to test your design using computer tools, and how to prepare completely for the physical implementation work.
Lessons Learned

Single-piece flow is the main goal, but it is not always attainable. Sometimes, you need to flow batches.

Resource calculations are done one process at a time.

Analyze the resources per process, under the light of standard time commonalities. If standard times are too different within a process, consider created sub-lines or cells.

It is best to develop the conceptual layout as a team exercise. Make sure that all the manufacturing functions are represented.

Develop a thorough workstation definition worksheet that you use to set up each individual workstation, and create Visual Work Instructions.

The line layout should also be an interactive exercise. We recommend the CAD interactive method. Have some fun with the layout.

Criticisms of the line are only allowed during the "Open Season" meeting. Once the season is closed, everyone gets behind it and works diligently to make it succeed.
So far in our presentation of the mixed-model line design process, you have been using “static” data, in the form of product lists, product forecast demand, Process Flow Diagrams, Standard Work Definitions, and the calculation of takt time and resources. Back in the “good ol’ days” as an industrial engineer, you would create a layout to the best of your ability, try to anticipate all of the issues that may arise, and physically put the production line in place. A debugging phase would start, in order to work out the bugs prior to launching full production. Things may go smoothly, or not, depending on the level of volume and mix variability, and your skill as a line designer.

Why Simulation?

Where are the opportunities to further improve on this methodology, to potentially reduce time, cost, and improve the quality of your line design? Leading companies around the world are tapping into new sources of insight, innovation and improvement by investing in simulation modeling of their product designs, manufacturing processes and office procedures. Michael Schrage in *Serious Play: How The World’s Best Companies Simulate to Innovate* says:

“The reason companies create simulation models is straightforward: these prototyping practices yield disproportionately high returns on

investment. The hard-dollar benefits can be plausibly measured in billions. Changing people or tweaking compensation incentives is not enough. Any organization committed to a speed-to-market philosophy inherently commits itself to ‘rapid prototyping’, if it has any hopes for success”.

Just as Lean Manufacturing methods have become a requirement in many industries, the intensity of global competition and Internet communications are driving Lean companies to speed up the rate of change. For example, “On the Internet, everyone knows you don’t have time to spell check.” The luxury of testing and debugging processes in the physical world is shrinking: by the time the process is tested, the customer may have gone elsewhere. Simulation time, including the time to develop the simulation model itself, runs at about 10 times the speed of actual time, and at less than 5% of the cost. If it takes ten months to physically implement a new production line, it should take less than one month to create the model and test the performance.

In addition to the need for speed, the human mind may not be capable of grasping the ramifications of complex, dynamic systems. This is especially true of mixed model line design. Jay Forrester, MIT’s father of system dynamics, observes:

“The mental model is fuzzy. It is incomplete. It is imprecisely stated. Furthermore, within one individual, a mental model changes with time and even during the flow of a single conversation. The human mind assembles a few relationships to fit the context of a discussion.”

Today the use of dynamic simulation modeling on computers moves the process improvement methodology several orders of magnitude forward. Not only are processes uncovered and mapped, as a core analysis tool, but their dynamic relationships can be modeled and tested, not once but many times. Multiple iterations of a model speed up the evolution process, at a low cost. In today’s world, any company that champions “speed-to-market” must also transform the speed at which it designs, tests and builds its simulation models as a part of its physical implementation effort.

Case Study One: The Value of Simulation

The difficulty in visualizing real-world results using static tools is highlighted in this real example. A major PC computer manufacturer was attempting to introduce a “Configure To Order” strategy, in order to provide faster customer delivery and reduce the need for finished products, as “The shelf life for computers is the same as for lettuce.” One of the unanswered questions was: how much staging space is needed to consolidate customer orders, so that the order can ship complete? A customer ordering a single PC is easy to manage, but what about larger orders?
What if a unit fails in burn-in? Do we hold up the entire order quantity until it passes? If so, where do we store the waiting units?

An estimate of the amount of space required was performed, using reasonable assumptions regarding order sizes, process yields, and the number of additional options that a customer might order. The result, agreed upon by two very reputable, and highly paid, consulting firms, was that approximately 25,000 square feet of staging space would be needed. At the 11th hour, a simulation team was brought in to evaluate the space requirements by creating a dynamic simulation model. In this computer model, orders were processed and staged until they were ready to be shipped, using the same assumptions that had been applied previously. The conclusions, however, were shockingly different. The simulation model showed that over 120,000 square feet of staging area would be needed, a space larger than the entire manufacturing area!

Unfortunately, the company ignored the results of the computer simulation, and proceeded with the original space assumptions. As predicted by the model, when production volumes approached the needed levels, the hopelessly undersized consolidation space filled with pending shipments, blocking the line. In desperation, the company abandoned their plan to configure-to-order on that line, outsourced the configuration work to a value-added reseller, and lost millions in the process. The moral of this story: if a well-designed model tells you something important, listen!

Spreadsheets and Simulation

Computer modeling and computer simulation are not new. In business schools in the late 1970’s, creating computer models was a state-of-the-art capability. Students walked their punch cards in a shoe box over to the mainframe computing center, and much later picked up reams of green-bar computer printouts, in order to review the simulation results. So what has changed since then? Models that once cost thousands of dollars to run, now cost pennies. It started with spreadsheets.

“Low-cost spreadsheet software effectively launched the largest and most significant experiment in rapid prototyping and simulation in the history of business. Financial models that had once cost thousands of dollars to design and build now cost thousands of pennies. The marginal cost of modifying complex spreadsheet models plummeted to near zero.” (Michael Schrage).

Within a few years of their introduction in 1979, millions of spreadsheet software packages were being sold annually.
Today, software systems that allow modelers to go beyond static spreadsheet analysis have exploded in affordability and capability. Powerful PC-based dynamic simulation tools can be used to create animated, 2-D and 3-D models of very complex environments. Computing power has increased exponentially, and large models can now be run on laptops. Keep in mind, even with these advances, the learning curve for developing a sophisticated simulation model from scratch remains steep.

The Mixed Model Line Design methodology has also matured. The methodology for designing and implementing Lean Manufacturing processes has evolved in the 1990’s, from a philosophical approach to a well-defined, mathematically-based science. The line design and material delivery design methods are well documented, although deep, hands-on experience always remains an important success factor. Lean practitioners can follow a proven path, to reduce the risk of failure.

Today, the combination of a mature line design methodology, as documented in this book, with mature simulation modeling tools, allows companies to reduce the time needed to create manufacturing simulation models from weeks to days to hours. It is possible to insulate end-users from the complexities of model creation itself, and allow them to focus on their processes and required data. The Lean Manufacturing rules regarding the use of buffers or In-Process Kanbans, the use of cross-trained flexible employees, and the introduction of Kanban “supermarkets” can be incorporated. What is, or what will be, the physical manufacturing environment can exist as a simulation model, and perform in a way that mirrors closely the eventual physical line.

Case Study Two: Achieving Design Goals

My first independent assignment as a Lean Manufacturing consultant to a large faucet assembly plant was not going well. I had followed the prescribed methodology closely, collected solid data, and the design was straightforward, a “no-brainer” of a line design, with a very short Takt time of 20 seconds. In spite of this apparent simplicity, and after three weeks of live experience, the line was still only producing about 80% of the designed volume. Instead of the expected 1,200 units per shift, we were getting around 950. Management patience was beginning to wear thin, and the order backlog was building.

Our Lean Manufacturing philosophy had indicated that we would strive to allow only one completed piece between each workstation, as a work signal and as a balancing tool. Mathematically that was the right number. Feeling guilty, we decided to experiment, and increase the number of pieces between each
workstation from one to three. This gave each worker the ability to continue to work for a longer period of time, before being required to stop. This additional time gave the operators a chance to balance their work more effectively, and helped them to overcome the delays that were happening. The result? Within one day, line production jumped 150 units per shift, to around 1,100. The cost of the additional inventory was negligible.

How would computer modeling have helped? A simulation model, created years later, that introduced real-world variability to our design quickly confirmed our earlier experience. The simulation model showed a throughput of 993 units, very similar to our actual experience. By adding two additional pieces between each workstation, the throughput jumped to 1,099, again confirming our actual experience. By increasing to 5 pieces, the throughput jumped up again to 1,168 per shift, an option that we didn’t try on the physical line due to space limitations. The designed capacity of 1,200 units per shift day was never achievable in the simulation model, or in real life, because of the inherent labor variability. We should have known this before the cells were implemented.

Simulations: Some Challenges

The use of simulation tools is not a panacea. The ease with which simulation models can be developed today does not mean that everyone is competent to build and interpret them. The underlying data and assumptions may be faulty. The simulation model may point out unanticipated results that management is not prepared to accept: 120,000 square feet of staging space, for example. Mixed model line designs and simulation models may also challenge entrenched organizational fiefdoms, when it becomes clear that departmental barriers need to fall in order to achieve a smooth flow process. The pride of ownership in the existing system may override anything that a computer model could say. The involvement of outside experts may be strongly advised, for both technical and political reasons.

Lean Manufacturing failures (and yes, there are some!) can often be attributed to a single weakness: a failure to understand variability, or the dynamic nature of the processes and people involved. Customer demand itself may be highly variable, and difficult to plan for. Work content time may be inconsistent, even for the same product. Changeover times may add a dimension of complexity that is difficult to understand. All of these variables can have a dramatic effect on the eventual outcome of a mixed model strategy. Many of these variables can be understood before implementation, by modeling the processes. Michael Schrage again comments:
“An organization’s culture and prototyping methods effectively determine its ability to profit from innovation. Organizations that can swiftly manage their models, prototypes, and simulations can and do reap tremendous competitive advantage. This has proven true in the past and will prove even more important in the future.”

The use of dynamic simulation modeling for mixed model line design has come of age. The cost-benefit ratio for model creation has shifted dramatically in its favor. As markets continue to grow more competitive, and competitors grow more innovative, the best hope for meeting the challenge in the future will be to build the right models as a part of your mixed model line design strategy.

The Impact of Variability

The formulas and methods discussed so far in this book have been static, i.e. they do not take into consideration the impact of variability of work time, that may result in delays and blockages in your flow. We normally deal with this uncertainty by over-designing the line, or making adjustments and corrections after the line is in place. This solution may be acceptable if the cost and ease of making changes is relatively low, and the capital investment required permits excess capacity. Adding or taking away a few desks or workbenches may be all that is necessary to modify an assembly or office process. A complex or capital intensive environment may not allow such changes after the line is physically created, and this is where the lessons learned from simulation can be so valuable. A computer model allows you to test your design using real world conditions, including changes in demand, inherent process variability, and adjustable buffer sizes. The outputs of the model include throughput volume, productivity, move distance and time, and a host of other variables. Figure 13.1 below shows both the dramatic impact of process variability on throughput, as well as the benefits of adding IPKs or inventory buffers to your line design.

The baseline design in Figure 13.1, which assumes no variability of work time, is based on a Target Volume of 60 units per day. With no variability, no buffers are necessary, since the units are able to flow from one workstation to another without delay, like a string of rail cars. Everyone completes their work at the same time, so there is no waiting or blockage. As soon as you add variability to the model, you begin to add time when the unit is either not available to be worked on, or you are blocked and cannot move the unit to the next station temporarily. The result is a drop in throughput and productivity. The more variation in the work time, the greater the negative impact.
Adding work time variability, as shown in Figure 13.2, compounds the problem, and throughput drops by more than 50%. The addition of IPKs shows an immediate improvement, and demonstrates the Law of Diminishing Returns. The first few pieces between workstations help throughput greatly, but adding more inventory quickly ceases to be beneficial.

As soon as you introduce variability into your model, it becomes impossible to actually reach the designed capacity. This is a powerful reminder that at the design stage, you need to set your Target Volume at a sufficiently high level to accommodate this reality. Flow lines actually perform best running at 80-85% of designed capacity. If you need to produce 100 units per day, then you should consider designing the line for 110 or 120 units per day. Otherwise you may be disappointed in your line performance!
Simulation: Specific Benefits

Benefit 1: Line Throughput and Balance

In a Lean Manufacturing line, throughput and balance are critical. In a “single-piece flow” environment, lack of balance and good flow can be devastating to production volumes and productivity. In a mixed-model line, where product times and options vary, achieving good balance is difficult using static analysis tools.

Lean Recommendation: Use dynamic modeling tools to analyze the proposed environment, using a mix of volumes and models. Create the best possible design and operating rules. Validate daily production mix in a simulation environment. Benefits:

- Greatly reduce design risk and uncertainty.
- Improve throughput 10-20%.
- Anticipate bottlenecks.

Benefit 2: Sizing In-Process Inventory Buffers

The use of in-process buffers (“In-Process Kanbans or IPKs”) is a powerful tool of Lean Manufacturing. Unfortunately the right number of pieces is not always 0 or 1. Sometimes adding inventory to the line results in dramatic improvements to flow and productivity, with a minimal additional cost. “Single Piece Flow” is not always the right answer or goal. Static IPK formulas don’t necessarily reflect the real world of mixed-model manufacturing.

Lean Recommendation: Measure queue and blockage time using dynamic simulation modeling, and reduce this time to a minimum with prudent use of IPKs. Balance improved throughput against the inventory investment. Benefits:

- Similar to #1. A major faucet manufacturer improved throughput 17% in 1 day through strategic resizing of buffers. Other companies have radically reduced in-process inventory by putting in place what was actually needed, and removing “just-in-case” inventory from the floor.

Benefit 3: Response Time Measurement

One of the key metrics of Lean Manufacturing is the factory response time, i.e. how long does it take to respond to customer orders? Traditional manufacturing uses inventory to manage customer response time, but Flow Manufacturers prefer build-to-order. Static response time measurements do not reflect real-world variability, and are useless as a measure of actual time required.

Lean Recommendation: Measure real-world response time using dynamic
Simulation modeling. This can be calculated and measured on a model-by-model basis. Mixed-model response time can also be measured in a simulation environment. Benefits:

• Establish realistic response time goals.
• Set realistic Finished Goods Inventory policies.
• Set customer response time (quoted lead time) more accurately.

Benefit 4: Identify Bottlenecks

Bottlenecks or constraints effectively set the maximum output of the line. Sometimes they are consistent and easy to identify, while in other cases the bottleneck may shift from one resource to another, depending on the product mix. Failure to manage bottlenecks can reduce throughput and productivity dramatically. Static calculations, based on a static mix of products, help identify constraints only for that mix.

Lean Recommendation: Test line designs with a range of products and volumes, and establish resource requirements based on the results of dynamic simulation modeling. Test for bottlenecks and constraints against daily production goals using dynamic simulation modeling. Benefits:

• Greatly improved understanding of bottlenecks, and a superior line design.
• Anticipate constraints and respond as part of a daily planning process.

Benefit 5: Process Improvements

Once the initial effort of putting a Lean Manufacturing line in place is complete, the never-ending effort of process improvement continues. With hundreds of improvement opportunities, it is difficult to set priorities and know where to begin. Focusing on the wrong areas may have little or no impact on customer response, throughput or productivity.

Lean Recommendation: Model process improvement suggestions using the dynamic simulation model of the line, and select the suggestions that maximize organizational goals. Common goals include response time reduction, inventory reduction, productivity, quality, throughput and floor space. Benefits:

• Set objective priorities for process improvement activities.
• Achieve target benefits quickly.

Benefit 6: Quality

Production yields have a dramatic impact on cost, productivity and delivery. Some of these costs are objective and easy to measure, while other quality impacts
are more difficult to assess. The impact of yields on throughput, for example, may be difficult to determine without simulation modeling. The impact of yields and scrap on productivity, response time and throughput can be measured using dynamic simulation tools.

Lean Recommendation: Incorporate yield and scrap assumptions into a dynamic simulation model. Use the resulting analysis to drive quality improvement initiatives in the most appropriate areas to benefit target metrics. Benefits:

- Understand and quantify the impact of yield and rework.
- Set priorities correctly for quality improvement initiatives.

**Benefit 7: Production Plan Validation**

Once a Lean Manufacturing line is in place, it is necessary to sequence demand to the line and manage it on a daily basis. As mix and volume change from day-to-day, it is necessary to assess the impact of these changes on the material flow, output and productivity. This is almost impossible to do well using static planning tools or spreadsheets.

Lean Recommendation: Prior to actual release to the factory floor, test production plans in a dynamic simulation environment. Identify bottlenecks and expected output in the model, and make appropriate corrections and adjustments as required. Additional resources, changing the sequence of work, or adding overtime are all possible adjustments that need to be made. Benefits:

- Optimize production plan prior to release to the floor.
- Anticipate problems and take corrective action.
- Achieve on-time delivery goals.

**Benefit 8: Valid Customer Delivery Dates**

As order backlogs grow and shrink, the actual time required to complete and deliver an order can vary dramatically. Quoting fixed delivery times (“5 days”) can result in unhappy customers when the actual production time, including other pending orders, exceeds that time. Trying to calculate actual delivery times in a dynamic environment, with varying backlog, is very difficult.

Lean Recommendation: Calculate dynamic completion dates using dynamic simulation modeling. Individual orders can be flagged, and a “best date” calculated using real-world assumptions and variability. Benefits:

- Dramatically improved ability to quote realistic delivery times.
- Quick re-planning as priorities change.
- Improved on-time delivery based on improved planning.
Benefit 9: Long-Range Capacity Planning

The need to anticipate growth is critical, especially when lead-times on capital equipment are long. Infinite capacity planning methods, like many MRP systems, are of no use. Finite capacity tools like Advanced Planning and Scheduling (APS), while powerful, are not always available and expensive. Lower cost solutions to capacity planning are needed.

Lean Recommendation: Changes to mix, volume and resources can easily be made using dynamic simulation tools. Testing various growth scenarios can be performed in a very short period of time through simulation modeling. Benefits:

- Low cost long-range planning tool.
- Highly flexible in analyzing various demand scenarios and resource requirements.
- Quickly identify key constraints.

Benefit 10: Sequencing Rules

Sequencing, or determining the optimum order of production, can be a key requirement for Flow Manufacturers. A failure to sequence correctly will have a negative impact on output and productivity. The need to sequence correctly increases as the complexity of the manufacturing environment grows. While dedicated lines will not require sequencing rules, in a mixed-model line it can be a make it or break it issue.

Lean Recommendation: Incorporate sequencing optimization algorithms to the dynamic simulation environment. Test proposed or recommended production plans in a simulation environment, and make changes as required. Benefits:

- Reduce the need for manual sequencing logic.
- Optimize flow and productivity.

Benefit 11: Productivity Assessment

In a Lean Manufacturing environment, workers are expected to “flex” or move to where the work needs to be done, based on visual signals. If they are able to do so, productivity should remain high in spite of these apparent movements and delays. It is not always possible to flex, however. There may be training and certification barriers, union requirements or physical barriers that prevent flexing. These constraints need to be identified and minimized. Certain line designs may restrict workers to no more than an 85% productivity level, due to barriers to flexing.

Lean Recommendation: Identify sources of delay and blockages using dynamic simulation modeling of the manufacturing environment. Statistics can be gathered
at an individual resource level. Appropriate corrective action, such as additional training, can be applied. Benefits:

- Maintain high productivity along with a high degree of flexibility
- Test line design and line performance against labor productivity goals.

**Benefit 12: Staffing**

How many people do you need on the line today? Too many people and productivity will drop; people may even get in each other’s way. Too few and production goals may be at risk. Static calculations of labor resources do not account for normal delays, variability and changeover times.

Lean Recommendation: One of the outputs of daily dynamic simulation modeling will be the number of labor resources applied to the plan. Actual staffing may be adjusted on a daily basis, depending on the results of the model. Overtime may also be required to meet production targets. Benefits:

- Correct daily staffing, based on dynamic simulation tools.
- Plan for overtime more accurately.
- Maintain high productivity.

**Benefit 13: Training**

A picture is worth a thousand words. Trying to explain “flexing” in words can be a thankless task until you draw a picture. Likewise, the concept of “flow” remains elusive, until we can see it. Most pictures or drawings are static. They don’t show work in motion, and people are required to imagine how things actually work.

Lean Recommendation: Create dynamic animation of proposed line designs and simulation models. Demonstrate the flow of products and material, and the movement of workers in the line. Show visually how the proposed changes will impact the model. Benefits:

- High level of buy-in and understanding.
- Reduced training time.
- Quick implementation tied to high understanding.
- Demonstrate strategy to customers, suppliers.

**Benefit 14: Management Buy-In**

The challenge of explaining proposed strategies to management is no less important. Management holds the purse strings, and is justifiably skeptical about the achievement of benefits. They’ve been burned before. These days you need
more than a fancy business plan to win approval for new projects.

Lean Recommendation: The creation of animation based on a computer simulation model is often done solely for demonstration or management buy-in purposes. After all, simulation data will be generated whether or not animation is used. The impact of seeing work in motion and understanding visually the flow of products and processes is incomparable. A well developed model accompanied by a strong visual presentation can be virtually unchallengeable. Benefits:

- Management understanding and buy-in
- Resource allocation approval
- Accelerated cultural change at high levels in the company

Simulation As A Requirement

If your line design project is relatively small, or the cost of making changes after the physical implementation is low, then the creation of a simulation model is probably not necessary. Otherwise, you need to put some serious thought into how you can build a model of your line design. Your ability as a line designer to understand the impact of changes in mix and volume, the effects of normal human variability, and the variable work content of the different models in your product family, is severely limited without the use of a modeling tool. Yes, this effort will require some time and money. Consider the alternative, however: a Mixed Model line that does not perform well in the face of variability and change.

Lessons Learned

Building a well-design simulation model requires some expertise and experience. It isn’t realistic to expect that every line designer will also be a simulation expert, but you want to have the expert available when you need him/her.

The challenge with Mixed Model Line Design is to design a line that can respond to changes in product mix, product work content times, product volumes and normal human variability.

It’s impossible to test a large number of scenarios without the use of computer simulation tools.

The cost of building a simulation model is a fraction of what it costs to re-do a physical production line, should that be necessary.
You now have the knowledge and tools to design the perfect value stream, with an emphasis on the word design. If you had been working on a house project, you would have a complete set of drawings, stamped by the architect and engineer, ready to hand over to a building contractor. You have not broken ground, and you don’t have a house you can live in yet, but by investing time and care into the creation of the design, your chances of getting the house that you want and can afford are greatly improved. A set of detailed plans will shrink the construction time, reduce the number of change orders (rework), and deliver a house that truly meets your needs.

Further Line Implementation Steps

In your Lean Design process you invested considerable time in identifying the products to be built, the relationship of processes required to build them, the time and quality standards needed, the calculations of takt and resources, and the creation of a balanced mixed model line. You incorporated Lean best practices into the design, including the ability to support single-piece flow, operator movement, optimized floor space, and visual tools. Like our house analogy, you have not actually built the new line yet, but by following a proven methodology, including validation with simulation modeling tools, the probability is high that the line will
perform as designed. There are three major areas of need that remain, which are beyond the scope of this book:

1. **The Physical Line Implementation.** This is the building contractor part of the line design effort. Tasks include assembling an implementation team, procuring necessary equipment, acquiring the physical space, creating and managing a detailed implementation plan, conducting tests and dry runs, training the workforce in any new procedures, and the creation of production planning and sequencing guidelines, among many other tasks. Working to a good plan is critical to the success of this phase.

2. **The Material Delivery System.** A complete Lean line design project is like a bird with two wings. In order to fly, it needs process design, as covered in this book, and a material delivery system, to be covered in a future book. These two topics are related, but mostly independent. The material delivery system includes both external procurement and working with outside suppliers, and the efficient delivery of that material to the location where it is needed. A complete implementation project would include a team focused exclusively on this part of the effort.

3. **Building a Lean Culture.** This is the toughest nut to crack, since it involves soft skills like leadership, company culture, the creation of a “Lean Management System”, and the engagement of the entire workforce. The good news is that a company can profit greatly from the implementation of a Lean line design, without needing to become another Toyota. Results, however, may vary. The best resource we’ve found on this subject is *Toyota Kata* by Mike Rother, a highly recommended read.

As a Lean professional, you have been introduced to a valuable body of knowledge that you can use for the rest of your career. In this final chapter, we will communicate what it takes to embed this knowledge firmly, earn some immediate benefits from it, and keep the information fresh and current. After all, the opportunity to work on a large, full-scale line design project only comes along infrequently. The opportunity to apply the mixed model line design methodology to the effort of Kaizen, or continuous improvement, is available at any time.

**Working on a Full-Scale Project**

The example you followed in this book was presented as a full-scale line design project, which might have been a line redesign or a “green field” new line. You followed all of the implementation steps, culminating in a conceptual line design, simulation testing, and finally a CAD drawing of the design. Unless you are a Lean consultant that has the pleasure of working on projects like this frequently,
chances are good that these design opportunities don’t come along often. This may only happen a few times in your career, so take full advantage of the experience.

One great opportunity to hone your line design skills, if you happen to work in a larger company and are not adverse to traveling, is to get yourself assigned to a line design team (or help to create one). The strategy is to maintain a high level of line design expertise within the company, and help to train less-experienced staff, by having a few “outsiders” from other plants on the implementation team for new projects. For a limited time you could be assigned to a line design project outside of your home plant.

Improving Existing Lines

Kaizen, or Continuous Improvement, is a core Lean value, and you will be able to apply your newly-acquired Lean Design knowledge more easily to continuous improvement efforts. Here are some examples of projects that are a good fit for mixed model line design skills.

1. An existing line has not been analyzed for awhile.
2. A feeder line is not performing well.
3. No one has applied Lean to office processes.

Don’t think that an improvement project needs to take a lot of time, or cover an entire line. Pick a small section of a line, even to the level of a few workstations, as a target for improvement. The key is to follow the implementation steps, as presented in this book, as the structure for your improvement project. Identify products and volumes, create Process Flow Diagrams, do the Takt Time and resource calculations, and apply the Error-Proofing and balancing tools. Improvements are virtually guaranteed.

The ideal structure for these kinds of improvement activities is the Kaizen Event, where a focused improvement effort takes place over a 3-5 day period. If the scope is too big to be accomplished in that time-frame, narrow it down. The Kaizen Event structure helps to avoid the never-ending project syndrome that is so common in many companies. Set the goals for the week, and accomplish them, and don’t let too many action items remain.

The Memory Jogger

You’ve heard about the Learning Curve, but what about the Forgetting Curve? It makes sense that if you don’t practice a skill, your knowledge of a subject
will begin to fade. The best way to preserve and expand your depth of skill in a subject is to practice it, ideally with ever more challenging applications. According to Malcolm Gladwell, in his book *Outliers*, it requires about 10,000 hours of continuously more challenging practice in a skill to become a “Master” of the skill, whether you be Mozart, or Bill Gates. As discussed above, take advantage of every opportunity to improve your skills with actual improvement projects.

A good additional technique for avoiding the Forgetting Curve is to review the material on a regular basis, as a series of short lessons. The term we’re using for this reminder system is “Memory Joggers”, which are delivered via the web in the form of weekly 5-minute lessons on various topics included in this book. As of this printing, the Memory Jogger program is not yet available, but it is under development and we expect it to be available by Q3 2014. If this is of interest to you, find out more and enter your name on a notification list at www.mixedmodellinedesign.com.

**Final Thoughts**

The website www.mixedmodellinedesign.com will be a forum and source for line design tools, including Excel workbooks for the examples shown in this book. Feel free to register and take advantage of these additional opportunities.

We first learned the Mixed Model Line Design methodology in the early 1990’s, and it has served us well in our Lean careers. The method has been applied successfully to literally thousands of line designs, in industries like aerospace, electronics, and even hospitals. Specific line design tools have improved, like the use of simulation modeling, but the methodology has proven to be fundamental and has withstood the test of time. We are confident that the method will prove equally valuable to you as well.
Appendix 1 The Lean Roadmap

- DEFINING THE LEAN ROADMAP
- THE FIVE PHASES
- THE LEAN DASHBOARD
- THE LEAN ROADMAP ONLINE
- DETAILED ROADMAP ELEMENTS

Mixed Model Line Design Roadmap Top Level

1.1 CREATE ASSESSMENT AND MASTER PLAN

Assess the current condition of business with a Lean Assessment. Develop Value Stream Maps and set target areas, schedule and expected benefits.

1.2 GATHER DATA

Compile data for quantitatively-based Lean Line design: products, volumes, machinery, work content and labor, and Process Flow Diagrams.

1.3 DEVELOP STANDARD WORK DEFINITIONS

Calculate Takt times, labor and machinery resources, and work locations required to build target volumes and mix.

1.5 DEFINE WORKSTATIONS

Lay out work in parallel or in sequence. Divide and balance work content. Design workstation layouts, material presentation and best work methods (GWIs).
1.6 CREATE CONCEPTUAL LAYOUT

Using Resource Calculations, prepare a paper-based conceptual layout of new Lean Line: processes, machinery, workstations, and IPKs.

1.7 DESIGN CAD LAYOUT

Adapt Conceptual Design to dimensionally correct layout. Detail material, work flow, IPKs, utilities, CAD or blue-prints for approval.

1.8 DEVELOP DEPLOYMENT PLAN

Set time line, budget and resources for Lean project. Sequence key tasks. Assign responsibilities, and dates. Use project management software.

1.9 CONDUCT TRAINING


1.10 BRING LEAN PROCESS LIVE

Set start-up strategy. Communicate goals and plans. Go “Line Live”. Start process improvements, measure results, and celebrate!

1.11 KAIZEN LINE PERFORMANCE

Correct line imbalances with waste reduction, moving work, resources, IPKs, time or inventory, and sequencing. Sustain.

1.12 PERFORM LEAN AUDIT AND CERTIFICATION


Assessment And Master Plan

1.1.1 COMPLETE SELF-ASSESSMENT TOOL

Conduct a Lean-focused assessment of Target Area, including financial and operating data, key metrics, and pre-Lean benchmarks.

1.1.2 DECIDE: USE OUTSIDE LEAN CONSULTANTS?

1.1.3 SELECT LEAN CONSULTING FIRM

If decision is to engage Lean consultants, screen for track record, deep experience, and compatibility.
1.1.4 APPOINT LEAN TEAM LEADERSHIP

Must be headed by a C-Level Champion, and directed by a Team Leader skilled in Lean principles and methods.

1.1.5 TRAIN MANAGEMENT IN LEAN PRINCIPLES

Conduct Lean training for management team – one to three days. Emphasize cultural issues, challenges of Lean change. Highlight the Lean Management System.

1.1.6 REVIEW CORPORATE GOALS & PAIN POINTS

Establish key performance issues to be addressed: additional capacity, faster cycle times, greater flexibility, better inventory turns, higher productivity, and additional floor space.

1.1.7 WALK THE GEMBA

As team, walk the Gemba and sequence of processes. Observe with “Lean eyes”: problems, opportunities, waste, hand-offs, and confusion.

1.1.8 PREPARE VALUE STREAM MAP

Draw Current State Value Stream Map. Analyze Value-Added vs. non-VA time, distances, and disconnected processes. Record process times.

1.1.9 DEVELOP FUTURE STATE VSM

Apply Lean Thinking for improvements to Current State Map. Draw Future State VSM showing these improvements.

1.1.10 QUANTIFY VALUE OF OPPORTUNITIES

For opportunities in Future State VSM, quantify benefits: lower inventory costs, new floor space for growth, incremental sales from short cycle times, etc.

1.1.11 PREPARE MASTER PLAN

Write Master Plan for Line Design. Include tasks and schedule, cost-benefit analysis, payback, assigned responsibilities. Obtain top management sign-off and ownership.
Data Gathering Process

1.2.1 CONFIRM TARGET AREAS

Revisit Value Stream Maps developed during Assessment, and confirm the chosen target areas. Obtain team consensus and management sign-off.

1.2.2 LIST ALL PRODUCTS AND OPTIONS

Create a comprehensive list of all products, models and options manufactured in the target area(s).

1.2.3 ESTABLISH VOLUMES AND MIX

Review sales history data, and chart trends and seasonality. Define mix and volume for Line Design. Management signs off on all forecasts.

1.2.4 DOCUMENT PROCESSES

Create a comprehensive list of all production processes in the target areas. Include scrap and rework. These processes should correlate with the Present State Value Stream Map.

1.2.5 LIST PRODUCTION RESOURCES

Create a detailed list of all production machinery, equipment, other fixed assets, and people in the target area.

1.2.6 CREATE PROCESS FLOW DIAGRAMS

For each product in target area, draw processes and sequences required to manufacture one unit. Use standard PFD format.

1.2.7 CREATE PROCESS FLOW MATRIX

Organize products and processes into a matrix format to document the relationships. Also called the “X-Chart”.

1.2.8 DEFINE INITIAL PRODUCT FAMILIES

Group products and models by process commonality. Each group will constitute a product family.

1.2.8 WRITE STANDARD WORK DEFINITIONS

For each product and process, define best work methods and call out critical quality checks. Collect time-study data for all work steps.
Standard Work Definitions

1.3.1 IDENTIFY TARGET PROCESS

The Process Owner should be involved in the creation of the SWD, along with operators, engineering and Kaizen Leader guidance.

1.3.2 ASSIGN DOC TEAM

The Process Owner should be involved in the creation of the SWD, along with operators, engineering and Kaizen Leader guidance.

1.3.3 ESTABLISH SWD FORM

A variety of different SWD forms are possible, depending on the type of work being measured. Select the appropriate form to use.

1.3.4 VIDEO PROCESS (OPTIONAL)

It is sometimes useful to videotape the process, in order to capture work times, and to be able to review the steps carefully.

1.3.5 DOCUMENT WORK STEPS

Document each discrete work step on the SWD form. Don’t worry about times yet. The level of detail needed will depend on the total work content and volume. This is not a time and motion study.

1.3.6 STANDARDIZE WORK STEPS

Observe a number of different staff workers, and review with them. Agree on the optimum sequence of step, especially when there are differences.

1.3.7 ESTABLISH QUALITY CRITERIA

Identify work steps with a quality risk, and either error-proof the step or flag the need for a check-do-check step.

1.3.8 RECORD WORK STEP TIMES

Take a sampling of times, with a variety of different workers. Capture average times, not the fastest or slowest worker. Classify the times appropriately.

1.3.9 DOCUMENT SUPPLIES

This information will be needed to design your supplies delivery, if needed.
1.3.10 DOCUMENT TOOLS AND EQUIPMENT

If specialized tools and equipment are needed for this process, capture this information on the SWD form.

1.3.11 CONDUCT STAFF REVIEW

Review completed document with the staff that does the work, and correct as necessary.

1.3.12 CREATE VISUAL AIDS

Create Visual Aids (if helpful) as a visual reminder of standard work.

1.3.13 CONDUCT STAFF TRAINING

Use both the Visual Aids and the detailed SWD as training materials.

1.3.14 ARCHIVE SWD IN DOCUMENT CONTROL

Ensure that the process document itself is stored in a safe location, and that it is under document control procedures. Changes cannot be made without approval.

Resource Calculations

1.4.1 ESTABLISH VOLUMES BY PRODUCT

Work from near-term sales forecast approved by management. Add percentage factor for capacity and to accommodate growth.

1.4.2 CALCULATE DAILY VOLUME BY PROCESS


1.4.3 ESTABLISH EFFECTIVE WORK MINUTES.

Calculate actual work minutes per shift, less breaks, lunch, and meetings, for each process. Verify shift policy.

1.4.4 CALCULATE TAKT TIME BY PROCESS

Extend Process Flow Matrix to include Available Work Minutes, divided by process volume.
1.4.5 PREPARE STANDARD TIME MATRIX


1.4.6 CALCULATE RESOURCES

For each process, calculate weighted average work time for mix of products. Divide by Takt time. Result will be number of resources required.

1.4.7 REFINE & REVIEW RESOURCE CALCS

Refine calculations: for workstations, round up or down according to CPI opportunities. For machines, minimum one location for resource.

Workstation Definition Process

1.5.2 DEFINE MACHINES IN PARALLEL

Confirm machine resources, capacities, demand. If multiple machines required at one process, typically best to arrange in parallel.

1.5.3 DEFINE LABOR SEQUENTIALLY

Confirm resources, work content, demand. Try to avoid single-station build, and arrange labor sequentially to allow Check-Do-Check quality control.

1.5.4 DEFINE WORK CONTENT BY STATION

Divide work content product-by-product. Refer to SWDs. In mixed model line, balance to number of workstations, not to Takt time. Provide materials, IPKs.

1.5.5 DETAIL DESIGN OF WORKSTATIONS

Specify tools to be provided. Coordinate with Materials Team on materials presentation, parts lists, Kanban chains. Build in good ergonomics, and convenient operator flexing to adjacent workstations.

1.5.6 CREATE GWIs

Create Graphic Work Instructions, and tie to Standard Work Definitions. Illustrate work steps, inspection points, tolerances. Use photos and colored graphics. Translations for multilingual workforce.
1.5.7 TRAIN AND CERTIFY OPERATORS

Determine staffing plan. Train operators according to SWDs and GWIs. Document skill levels on departmental Certification Board. Establish certification for operators, trainers, supervisors.

Conceptual Layout

1.6.1 GATHER DATA & VALUE STREAM MAPS

Gather and review all work to-date. Revisit the Present and Future State Value Stream Maps and improvement areas.

1.6.2 PREPARE TEAM & WORKSPACE

Schedule ample time for Conceptual Line Design session. Lay out work area, or wall space with butcher paper. Provide pens and colored sticky notes.

1.6.3 DEFINE THE HIGH-VOLUME PATH

Referring to the Process Flow Matrix, with volumes, define the sequence of processes carrying the highest unit volume. Lay out this path with sticky notes.

1.6.4 LAY OUT FEEDER PROCESSES

With the Main Path defined, fill in the feeder processes and rework loops. Ignore physical layout constraints such as floor space or walls.

1.6.5 LAY OUT RESOURCE DETAILS

Move to next level of detail. Using resource calculations, set machine locations, numbers of workstations. Decide parallel vs. sequential layout of resources.

1.6.6 PLAN MATERIALS AND IPKs.

Plan material presentation to workstations, movement between processes, and IPKs. Display detail on the butcher paper layout chart.

1.6.7 REVIEW CONCEPTUAL LINE DESIGN

With Conceptual Line Design displayed, “walk products through the line” to verify processes, sequence, volumes and options. Make adjustments as required.

1.6.8 DOCUMENT CONCEPTUAL DESIGN

Photograph Conceptual Line
1.6.9 COMPLETE CONCEPTUAL LAYOUT

Design on butcher paper, and transfer to hand-drafted or CAD document. Obtain sign-off from team and senior management.

**Cad Layout**

1.7.1 REVIEW CONCEPTUAL LAYOUT

Gather Conceptual Layout and all supporting documents, lists of processes and resources, PFDs, and calculations.

1.7.2 PREPARE FLOOR PLAN CAD OR BLUEPRINT

Working with CAD files or a paper blueprint, establish accurate image of facility including floor plan, columns, fixed equipment, utilities and doors.

1.7.3 DECIDE: DESIGN WITH CAD OR ON PAPER?

1.7.4-A SET UP CAD SYSTEM AND PROJECTOR

Appoint skilled CAD operator for team. Set up in conference room with CAD system, floor plan, projector, screen and ample workspace.

1.7.4-B SELECT SCALE AND CUT OUT MODELS

Recommend largest scale possible: 1 inch to 1 foot. Cut accurately-scaled layout models for all equipment, racking, fixed assets and IPKs.

1.7.5 LAY OUT PROCESSES ON FLOOR PLAN

Prepare first-cut layout of all processes, using CAD or paper models. Replicate, as closely as possible, the Conceptual Line Design. Resolve compromises.

1.7.6 DETAIL THE PHYSICAL LAYOUT PLAN

With processes located, add detail for aisles, storage, crane reach and load, electrical, and ceiling clearances. Call in Engineering and Maintenance for review. Document thoroughly on CAD or paper layout sheets.

1.7.7 PERFORM ON-SITE REALITY CHECK

With detailed Layout Plan, walk the facility, verifying locations, equipment sizes, utilities, clearances, and other issues. Include Engineering, Maintenance.
1.7.8 PREPARE LAYOUT DOCUMENTS

With all details complete and confirmed, prepare final documents for Layout Plan: CAD print-outs in large scale, or blueprints. Copy, post and distribute as required.

Deployment Planning

1.8.1 REVIEW LINE AND PHYSICAL LAYOUT

Gather Layout Plan documents, resource calculations, and lists of production equipment, fixtures, and other assets required by Line Design.

1.8.2 PLAN EQUIPMENT PROCUREMENT

Create list and capital budget for all new equipment. Set specifications, capacity, footprint, investment. Obtain Management approval, and issue POs and contracts to meet time lines.

1.8.3 PLAN FACILITIES IMPROVEMENTS

With Maintenance and Engineering, determine all work required on facility: utilities, remodeling, moving racks, and HVAC. Decide on in-house labor or contractors.

1.8.4 SET DEPLOYMENT SEQUENCING

Working with full team, determine long lead-time tasks, critical path, and preferred sequence for moves and installation of equipment.

1.8.5 BUILD PROJECT MGMT SPREADSHEET

With action items and sequences set, build project management spreadsheet or Gantt chart. Recommended to use PM software.

1.8.6 ASSIGN DATES & RESPONSIBILITIES

With project management spreadsheet loaded, determine required milestones and dates. Assign responsible people.

1.8.7 APPROVE CAPITAL & EXPENSE BUDGETS

For all Capital and Expense outlays not already approved, obtain Management sign-off and issue POs and contracts.

1.8.8 LAUNCH PHYSICAL LAYOUT & MOVE

Deployment of Layout and Move is ready for launch.
Training

1.9.1 REVIEW ALL WORK DOCUMENTATION

Gather all documentation of work content and steps in the Line Design: Workstation Definitions, SWDs, and GWIs.

1.9.2 DEFINE SKILLS BY PROCESS / STATION

For every process and workstation in the Lean Line, detail and document the skills required.

1.9.3 ASSESS CURRENT SKILL LEVELS

Assess the skill levels of all operators in the new Lean Line area. Create a department Certification Board with information by skill and operator.

1.9.4 CONDUCT “LEAN OVERVIEW” TRAINING

Conduct “Lean Overview” training for all operators and supervisors. Emphasize benefits of the Lean workplace. Hands-on and role-playing for flexing, IPKs, Kanban bins.

1.9.5 TRAIN TO THE WORKSTATION

Train for process-specific work. Materials include SWDs, GWIs, Workstation Definitions, parts lists, and key quality checkpoints. Check-Do-Check.

1.9.6 CERTIFY OPERATORS

Supervisors and area leaders observe operators at work, coach where required, and certify that work is being performed correctly. Record on Certification Board.

1.9.7 SUSTAIN SKILL LEVELS

Determine interval for renewing skills: six to twelve months. Include dates on Certification Board to schedule refresher or recertification.

1.9.8 START LEAN PROCESS LIVE

Lean Process Live

1.10.1-A VERIFY DEPLOYMENT PLAN COMPLETE

1.10.1-B VERIFY TRAINING PLAN COMPLETE

1.10.2 DETERMINE START-UP STRATEGY
Decide to launch with “Dry” or “Wet” Line - all at once, or process-by-process? If by process, then start at line end and work upstream. Weekend or shutdown? Need to build inventory?

1.10.3 SET & COMMUNICATE METRICS

Establish and communicate daily unit volumes and Takt times. Install white boards to display ramp-up schedules, milestones, and actual results.

1.10.4 CONFIRM PARTS AND KANBAN CHAINS

With Materials Team, verify that all parts and materials are in correct locations. Check material presentation in work-stations throughout the Lean Line. Walk and audit the Kanban chains.

1.10.5 COMMUNICATE AND BUILD BUY-IN

Communicate plans thoroughly, emphasizing value of Lean project. Anticipate and address operators' concerns.

1.10.6 PREPARE THE WORK SPACE

Clean and paint workspace for fresh look. Install visual factory aids. Set the tone: “It’s a New Day.”

1.10.7 “LINE LIVE DAY”

Begin single-piece flow. Start modestly and build up to designed production rate. Management presence and coaching are crucial to success and buy-in.

1.10.8 BEGIN PROCESS IMPROVEMENT

Appoint quick-response team to identify, document and correct any line issues that appear. Begin Continuous Process Improvement function.

1.10.9 CELEBRATE “LEAN LINE LIVE”

Identify a short-term milestone (week or month) to celebrate. Emphasize culture change, CPI, and organization buy-in.

**Line Balancing Work**

1.11.1 EVALUATE LINE BALANCE

Look for indicators of line imbalance: WIP piling up, bottlenecks, constraints, idle operators, poor volume and throughput.
1.11.2 APPLY LINE BALANCING TOOLS

For each instance of line imbalance, analyze causes, and apply one or more appropriate line balancing tools.

1.11.3-A ELIMINATE WASTE

Identify and eliminate NVA activity. Focus on standard work times. Assign Kaizen teams.

1.11.3-B RELOCATE WORK

Observe imbalance area, and wait for learning curve to level out. Focus on labor steps and work content. Use input from operators and supervisors.

1.11.3-C ADD RESOURCES

Calculate investment in new process machinery. May be required by process variability or capacity needs.

1.11.3-D INSTALL IN-PROCESS KANBANS (IPKs)

Calculate IPKs, and use when actual times vary around Takt. A few inventory units can significantly smooth flow.

1.11.3-E ADD INVENTORY AND/OR TIME

Calculate inventory required. Can be used when average work time exceeds Takt. Build inventory up- or down-stream, plus additional work time.

1.11.3-F INTRODUCE SEQUENCING

Create and use sequencing in mixed-model line with differing work content. Sequencing smooths flow, helps avoid jamming and starving workstations.

1.11.4 IMPLEMENT KAIZEN TOOLS

Following implementation, observe and confirm improvements. Monitor, adjust and fine-tune the Lean Line’s balance, flow and throughput.

Audit & Certification Process

1.12.1 COMMIT TO LEAN AUDIT PROCESS

At least six months following “Line Live,” leadership decides on a formal evaluation of the Lean project’s measurable results and sustainability.
1.12.2 DECIDE: USE OUTSIDE AUDITOR?

1.12.3-A SELECT OUTSIDE AUDITOR

As with earlier decision regarding consultants, consider the value of experienced outside experts in evaluating and certifying the Lean project.

1.12.3-B PREPARE FOR LEAN AUDIT PROCESS

Select Audit Task Force. Gather and review all documents, checklists and other materials used at project inception.

1.12.4 EVALUATE NEW “CURRENT STATE”

Are all action items on Master Plan completed? Review Line Design, Resource Calculations: does Line produce designed volumes with calculated resources?

1.12.5 MEASURE PROGRESS TOWARD GOALS

Is there measurable progress towards corporate goals: inventory turns, increased productivity, shorter cycle times? Has this progress produced the expected Return on Investment?

1.12.6 CHECK THE CULTURE

Is there visible change in the facility: 5S conditions, orderliness, tempo, Visual Factory indicators, employee attitudes, CPI and Kaizen activities?

1.12.7 ADD UP THE SCORE

Retake the Self-Assessment questionnaire used before. Analyze scores: are they incremental gains, or a Lean transformation?

1.12.8 CERTIFY AS LEAN

When all results of audit and review are satisfactory, determine that the target area is “Lean-Certified.” Plan an event to celebrate the team’s success.

1.12.9 SUSTAIN AND IMPROVE

Referring to the Value Stream Maturity Model, decide on several priorities for ongoing Lean work. Sustain the Lean Line’s gains and culture.
Lean is not a new or radical concept for the 21st century, and has evolved since its humble beginnings in the late part of the 1800’s. At the beginning of the industrial revolution, manufacturing companies were challenged with the management of new machines and their enormous production output. Machine output far outpaced human beings doing the same work. The textile industry was one of the first to introduce large-scale machinery, with its massive cloth-weaving machines. At that time, products requiring the shaping or cutting of metals were still labor intensive, and labor productivity was a serious management concern.

Around 1885, these technology and management issues were addressed formally when Frederick Winslow Taylor began publishing his work. What Taylor proposed, was that all manufacturing work be analyzed and broken down into individual tasks, so the tasks could be shortened or eliminated. The application of this scientific method, coupled with the time study techniques introduced by Frank Gilbreth, led to great increases in the efficiency of industrial work. Taylor set about proving his methods in different industrial applications, focused on finding the one best way, or what we now call standard work.

Taylor’s methods were put to the test by Henry Ford’s large motor car plants. Ford’s first successful production model was produced in 1903, but his fame grew with the first full production year of the Model T in 1908. By 1913, ten years after
launching the company, Ford was producing half of the cars made in America. Ford proposed building an automobile that would be “a car affordable for every American”. The main challenges were productivity, cost, and finished product availability. Productivity was improved by having the car pulled through the plant at a constant speed, while groups of parts were accumulated for the workers to assemble. In this production line, workers normally repeat only one or two tasks. Ford had proposed that “a man must not be hurried in his work”, so the timing and balance of the individual tasks was critical.

Productivity was further increased when Ford introduced the moving assembly line for chassis assembly. Total assembly time was reduced from 12.1 hours to 1.5 hours. Productivity improved and the goals of cost reduction and increased availability were reached using this method. A remarkable achievement during the production of the Model T was the fact that as the production volume increased, the selling price was continually reduced, beginning at $850 in 1909, to $260 in the final full production year of 1926.

One of the early visitors to Ford’s River Rouge plant was Mr. Kiichiro Toyoda of Japan, who had been asked by the Japanese government to begin producing vehicles as an extension of his successful textile business. His founding of the Toyota Motor Company in 1937 was inspired by his visit to the River Rouge site. The huge capital investment that would have been required to fully emulate the Ford plant was impossible for Toyota, and the need to compete with fewer resources provided the motivation for the improvements and changes that were to later come.

Driven by customer demand, product variety became the next goal in manufacturing during the 1920’s. Most manufacturing facilities struggled to gear up for production of new product models. Delays of six months for the retooling of assembly lines were common and expected. Ford spent $100,000,000 and took 18 months to introduce the new Model A in 1927. Until this time, manufacturers had focused primarily on labor productivity to achieve a competitive cost advantage.

Innovations in technology became the new productivity tool that allowed many manufacturers to remain competitive. This period marked the advent of technological changes in machine tool cutting points, synthetic abrasives, and multiple rotary cutting points, particularly in lathes and milling machines.

Manufacturing through the 1930’s and 1940’s was still driven by large quantity production runs, although runs like the 17 years for the Model T Ford were no longer possible. Consumers were more and more the drivers of change in a product’s life cycle. The demand for specialized products began to grow in
earnest following World War II. Not only were products more specialized, but they also had much shorter life cycles. This evolution in production methods, led by improvements in machine and labor productivity, marked the beginning of the mass production era in the U.S., with its flagship production method *batch production*.

In batch manufacturing, production quantities were based on what would make the machines most productive, and not necessarily what the market wanted to buy. This subtle change in focus pitted manufacturing departments against marketing departments throughout industry. Batch manufacturing allowed machines to be productive when building large quantities of the same product, but batch processes created problems for manufacturing when building a mix of different products. Solutions to this dilemma were found in the 1950’s, in a discipline called Group Technology. Group Technology proposed that manufacturing processes focus on the similarity of material shape, size, or method of manufacture. The focus on materials gave limited advantages, so the discipline was expanded to include machines and operations. This evolved into what we know today as *Cellular Manufacturing*, where a group of machines and people have autonomous authority over administration, planning, and operations to build a specific family of products.

While many companies in the United States pursued these disciplines, a different set of techniques was maturing in Japan, lead by the Toyota Motor Company. At Toyota, it was contended that the standard thinking of \( \text{Cost} + \text{Profit} = \text{Sales Price} \) was incorrect. Toyota believed that \( \text{Profit} = \text{Sales Price} - \text{Costs} \), highlighted the manufacturer’s market role as a “price taker”, rather than an influential force in price setting. From this premise, Toyota began to create a manufacturing system focused on the management of costs. Cost became translated as waste, and wastes of all varieties were targeted for elimination. Target areas included work in process inventory and safety stock. While many companies in the United States and Europe were attempting to calculate the optimum batch sizes for production, Toyota was working diligently toward the goal of building a mix of products in a one-piece flow, i.e. a batch size of one. Building a mix of products in a one-piece-flow satisfied many key objectives for Toyota: raising productivity, reducing costs, reducing the need for working capital, including fast customer response time.

From an almost bankrupt position in 1949, and a modest total production of only 3,000 vehicles in 1950, Toyota began to gather and document all of the information in the manufacturing field that was available. In that year, Taiichi Ohno became the manager of Toyota’s Honsha machining plant, and Shigeo Shingo began his work as an engineering consultant within that organization. One of the key documents uncovered by Mr. Ohno, was a 1912 Japanese translation of Frederick Winslow
Taylor’s *Shop Management and the Principals of Scientific Management*, published in English in 1911. Drawing on this and other sources, American and Japanese, Ohno began to mature and apply these concepts to what would later be known as the *Toyota Production System*.

During the reconstruction period following the war, Japan received help from several quality experts from the U. S.: W. Edwards Deming, W. A. Shewhart and Joseph Juran. While Shewhart declined the invitation to work in Japan directly, both Juran and Deming spent considerable time there, teaching Japanese managers about statistics and quality. Deming has been credited with inspiring the “Japanese Industrial Miracle” and the highest prize for quality in Japan today is called the Deming Quality Award.

In Japan in the 1960’s, Toyota, Honda and other Japanese manufacturers were preparing for their assault on the American automobile market. In 1955, 95% of the automobiles sold in America were American made, but that would soon change. Extending its production philosophy further, Toyota introduced the concept of Quality Circles in 1962. Active participation by production workers to analyze and discover the root cause of problems, and then implement a solution, introduced the practice of Kaizen or continuous improvement. The company began to receive an average of one improvement suggestion per worker per week, or thousands per year. Toyota finally won the Deming Quality Award in 1965.

Through the 1960’s and into the 1970’s, Japanese and American philosophies of manufacturing developed down separate paths. In the U. S., manufacturing companies looked for better ways to manage batch production, while in Japan companies were finding ways to allow one-piece-flow of a mix of products. The results of these different techniques came into clear focus during the 1980’s, when many product markets within the United States and Europe came under pressure from Pacific Rim manufacturers. Foreign products introduced into the American market were unquestionably cheaper and of higher quality. In order to survive, American manufacturers began to search for better ways to compete, and to search for the manufacturing secrets of these foreign competitors. Theories abounded for the extraordinary success of Pacific Rim manufacturing, including cultural explanations for the differences between Japanese and American products.

As books were translated and digested, and as more trans-Pacific travel took place, the specific tools and techniques being used by these foreign competitors became more widely known. In the late 1980’s and 1990’s, many American companies abandoned batch manufacturing in favor of the more responsive method of Lean Manufacturing, and also began to pursue the goal of being able to flow a mix of products one unit at a time.
Taiichi Ohno proclaimed in 1971 that his ambition to complete the Toyota Production System had been accomplished. As the “secret” information from abroad began to be documented and taught, various schools of thought began to develop in the United States. One school of thought adheres strictly to the methods presented by Toyota and the Toyota Production System. The school of Lean Manufacturing, similar to the Toyota approach, has been adapted in the U.S. by many companies, especially the automotive industry. A 1985 business novel *The Goal* by Eli Goldratt launched the concept of Theory of Constraints, with a focus on throughput maximization. The list of books and buzzwords continues to grow.

Lean Manufacturing today is a widely proven, non-culturally based technique that links elements of work, so they are carried out without bottlenecks or delays. Although the products themselves vary in volume, in type, and in mix, the techniques remain the same: definition of the processing flow of a product, standard work definition at a detailed level, and designing the production flow line. When the line has been designed for product flow, a set of tools that balance the work to a calculated flow rate or takt are employed. As the design and balance of the line is completed, the flow of material and calculation of material quantities, using Kanban techniques, are executed. Using these basic tools, a flow processing line can be created and implemented successfully. From that point forward, the key to long-term success is the enterprise’s ability to sustain the gains from the Lean implementation. Sustainability cannot be purely people dependent, as that puts the company at risk when people move on. Sustainability has to be rooted in a set of tools for enterprise-wide training and accountability in the Lean tools.
It is important that our process improvement efforts show results, and these results should be communicated in dollars, as much as possible. In some cases quantifying results is easy: productivity, inventory, overtime, scrap and rework are categories of improvements that convert to dollars without too much challenge. Other types of improvements are harder: office processes, lead-time, cycle time reduction and inventory accuracy are examples of improvements that are harder to express in dollars. A dollar benefit exists for these types of improvements, but the link to dollars is indirect. The purpose of this section is to describe a method for estimating and quantifying benefits for most of the common categories of process improvements.

Remember to project benefits sufficiently far into the future. If the benefit is expected to continue to yield results, compared to maintaining the status quo, then a reported result over a reasonable period of time makes sense. For example, you could calculate benefits “over a three year period” instead of limiting the time frame to a year or less.

Some of the measurements require a “dollars per incident” value in order to convert the measurement to the common denominator. This number is usually not readily available. This dollar value will typically not show up, at least directly, on a Profit & Loss statement for the company. Assuming that the management team
agrees that the category in question is worth improving, the “dollars per” figure is simply a management tool to put a relative weight or value on the benefits achieved. The management team should also agree that the value is reasonable. Draw on accounting personnel to help come up with the “dollars per”. This will add legitimacy to a number that may otherwise be questioned.

Manufacturing Cycle Time and WIP Inventory

Data Required: 1. Current WIP Inventory Value. 2. Calculation or estimate of cycle time reduction. Measurable through tagging or WO tracking.

How To Quantify: WIP inventory is tied to cycle time reduction. A reduction of 50% in cycle time equates to a 50% reduction in WIP inventory. Divide the new cycle time value by the previous cycle time value, and multiply by the current WIP value. This gives you the projected new WIP value. Subtract from the previous WIP dollars to calculate savings.

Cycle Time and Customer Response

Data Required: 1. Calculation or estimate of cycle time reduction. 2. A dollar value estimate of the value of a day of cycle time, for use as a management tool. Cycle time reduction in most cases has a positive correlation with increased productivity, sales and market share. You also need a Dollars Per Day value that reflects this opportunity realistically.

How To Quantify: Multiply the number of days of cycle time reduced, times the Dollars Per Day value.

Example: Current line has a cycle time of 5 days. A reduction in cycle time to 2 days has been achieved. Management has determined that a day of cycle time is worth $15,000 in increased productivity, sales and market share. A 3 day reduction is measured at $45,000. This number is used to assess ROI potential, and to compare various improvement alternatives.

Raw Material

Data Required: Current inventory value of raw material, and projected level of raw materials after the improvement.

How To Quantify: Directly measurable. Reductions are normally the result of supplier Kanban systems and improved material management. Reducing WIP
will not necessarily reduce raw material. The difference in raw material can be directly calculated if Material Kanban is introduced.

**Example:** A new Kanban 2-container system contains an average of $123,000 in material, once it is in place and being used. The current inventory level for these materials is $223,000, so a reduction of $100,000 is expected.

**Note:** Report working capital (inventory) reductions independent of cost reductions. Don’t add the two together. Inventory is a balance sheet item, while costs impact the Profit & Loss statement. Apply a *Cost To Carry Inventory* percentage to estimate bottom-line savings related to raw material reductions. A reduction of $3.5M, using a cost-to-carry factor of 20%, should result in bottom-line annual savings of $700,000.

### Finished Goods

**Data Required:** Current Finished Goods Inventory in $. To be achieved through reduction in cycle time, resulting in reduction in safety stock levels. Reducing cycle time by itself will not automatically reduce Finished Goods, without changing safety stock levels.

**How To Quantify:** Estimate reductions in FGI in $. Safety stock levels could change in relation to cycle time reductions.

**Example:** Apply a “Cost To Carry Inventory” percentage to estimate bottom line savings related to Finished Goods reductions. A reduction of $1.4M, using a cost-to-carry factor of 18%, should result in bottom-line annual savings of $252,000.

### Direct Labor Productivity

**Data Required:** 1. A record of units produced (outputs) and labor hours consumed (labor input). 2. An estimate or measurement of productivity improvements. If the company is gathering labor hours via a work order system, the dollars per unit can be collected from the work order system.

**How To Quantify:** Multiply Units Per Labor Hour times a measure or estimate of productivity improvement. Dollars Per Labor Hour are also used. This can be gathered through sampling actual production times.

**Example:** The company consumed 1,000 labor hours to produce 175 units in a day. The hours per unit measure of productivity is 5.71, down from 6.71. Multiply the labor hour difference or improvement × the average hourly wage × number of units. 1.0 × $18.75 × 175 = $3,281 savings per day, or about $787,000/year.
Scrap and Rework

**Data Required:** 1. Current period scrap and rework dollars. 2. An estimate or measurement of improvement in scrap and rework.

**How To Quantify:** Apply a percentage improvement to the current scrap and rework dollars. This benefit can also be measured directly if before and after scrap dollars are available. At the end of a Kaizen event, you use an estimated reduction figure, based on engineering judgment.

**Example:** The company reported $2.5 million in scrap and rework last fiscal year. A sample of yields after process improvement changes suggest a 50% reduction in scrap and rework costs. The benefit projected over a year would be $1.25 million.

Overtime

**Data Required:** 1. A measure of current overtime paid, over the last year. 2. A projection or actual measurement of overtime reduction.

**How To Quantify:** Apply a percentage improvement to the current over-time dollars.

**Example:** The company has spent $500,000 on overtime in the last fiscal year. Improvements in schedule attainment, cross-training and improved productivity are expected to cut overtime by 1/3. The reduction in overtime costs amounts to $133,000, or $500,000 over a three year period.

Changeover Reduction

**Data Required:** 1. A record of actual changeover times by machine or line. 2. A measure or projection of the reduction expected. 3. Dollars per production hour.

Note that there are multiple benefits to changeover reduction, and an increase in available capacity is only one. The company can also increase the number of changeovers and reduce lot sizes. Productivity is typically improved.

**How To Quantify:** Dollars per production hour, times the increased number of hours gained over a 12 or 36 month period.

**Example:** The line is changed over 12 times a month, with an average changeover time of 4 hours. A SMED program reduces the changeover downtime on the machine to 1 hour. The production time on the line is valued at $5,000/hr. The total savings over a 12 month period is: 12 (times a month) × 3 (hours saved) × 12 (months in a year) × $5,000 = $2, 160,000.
Inventory Accuracy

**Data Required:** Using a sample of inventory items, count the number of parts and compare the computer inventory balance with the number counted. If the counted quantity is within a pre-defined tolerance range, it is a “hit”, and a quantity outside the range is a “miss”. The total number of hits, divided by the total number counted, is a measure of inventory accuracy. To calculate the benefits, it is necessary to establish a cost of inventory inaccuracy, in dollars. Costs include delayed shipments, wasted time looking for materials, material write-offs and losses, etc. Quantify this cost as a dollar figure that management will agree to. Multiply each percentage of inventory inaccuracy by this number, for a calculation of total dollar impact. Note that this is a management tool only!

**How to Quantify:** Change in inventory accuracy percent, multiply by the “dollars per percentage inventory inaccuracy”.

**Example:** The company has agreed that every percentage point of inventory inaccuracy costs the company $10,000 in late shipments, inventory write-offs and lower productivity. Inventory accuracy is improved from 82% to 93%. Benefit = 11% × $10,000 or $110,000.

Office Processes

**Data Required:** The two main measurements for office processes are cycle time and defect rate. Cycle time can be documented using the “tagging” technique of moving a log sheet along with the item (RFQ, customer order, etc.) and logging in work and queue times. The defect rate for office processes is not normally tracked, and a tracking system needs to be created to capture this type of information. In addition, you need a “dollars per incident” or “dollars per day” value in order to convert these two measures to dollars.

**How To Quantify:** Multiply “dollars per incident” or “dollars per day” times the number of incidents or days reduced.

**Example:** The management team has agreed that an error in the order entry process costs the company $1,000 in additional work, errors in production, customer goodwill, etc. The number of defects has been reduced from an average 47 errors per month to 12 per month, for a net change of 35. This improvement be quantified at $1,000 x 35 or $35,000 per month. This also equates to $1,260,000 over a three year period.
Preventive Maintenance

**Data Required:** 1. An accounting of maintenance time. A record of equipment downtime as a percent of total available time. 2. An estimate of the cost of downtime. This could be the same number used to calculate setup reduction benefits: the dollar value of a production hour. This number can be easily developed by manufacturing and accounting, typically based on the potential output of the line during a given period of time.

**How to Quantify:** Dollars per production hours, times the increase in available hours.

**Example:** A robust PM program has reduced equipment downtime due to unexpected failures from 44 hours a month to 7, for a net change of 37 hours. A production hour has been valued at $12,000. The benefit would be 37 hrs. times $12,000 or $444,000 per month.
<table>
<thead>
<tr>
<th>Industry Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Activity Based Costing</td>
<td>A system where the costs of specific work centers are accumulated and subsequently allocated as a percentage of overhead costs assigned to each product through the standard cost build-up process.</td>
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<tr>
<td>Andon</td>
<td>Is a system which alerts management and workers to a problem or a condition on the line. In many cases it is an electrical board which lights up to show at a glance the current state of work operation. Andon boards allow speedy corrective action to be taken by supervisors when a problem arises. Besides indicating abnormal situations, some Andon boards provide work instructions (such as quality checks, change of cutting tools, and conveyance of parts) and job progress information.</td>
</tr>
<tr>
<td>Backflush</td>
<td>The process of performing inventory transactions to update inventory balances upon completion of one finished unit. At the point of completion, at the end of the line of one complete unit, a transaction occurs incrementing the inventory quantity in finished goods by one unit while simultaneously reducing component inventories by item and quantity listed on the Bill of Material.</td>
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<td>Term</td>
<td>Description</td>
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<tr>
<td>Balancing Tools</td>
<td>The tools used to refine the workstation definition. These include: Elimination of waste, Relocation of manual work, Addition of resources, In-Process Kanbans, Inventory and Time, and Production Sequencing.</td>
</tr>
<tr>
<td>Bill of Material</td>
<td>A listing of all the sub-assemblies, parts, and raw materials that go into a parent assembly showing the quantity of each required to make that assembly. For an MRP system to perform time-phased and shop floor control routing, the bill of material must be indented to simulate the manufacturing process and establish start and due dates for each department of the manufacturing process.</td>
</tr>
<tr>
<td>Certification</td>
<td>The acknowledgment of competency for a manufacturing operator recognizing the ability to perform the standard work definition identified at a primary workstation plus one upstream and one downstream within a Takt time while performing the defined quality criteria.</td>
</tr>
<tr>
<td>Certified Supplier</td>
<td>A supplier capable of delivering high quality materials on time to a kanban signal.</td>
</tr>
<tr>
<td>Changeover Matrix</td>
<td>A “From-To” matrix documenting the changeover times from one product to another product built in the same process.</td>
</tr>
<tr>
<td>Changeover Time</td>
<td>The time required to prepare a process to start production on a new model.</td>
</tr>
<tr>
<td>Configuration Traveler</td>
<td>A document that physically accompanies each unit of production to indicate the unique configuration of that particular unit.</td>
</tr>
<tr>
<td>Continuous Flow Process</td>
<td>One of three basic requirements of Just-In-Time. This means eliminating the stagnation of work in and between processes and carrying out one-piece-flow production.</td>
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<tr>
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<tr>
<td>Continuous Process Improvement (Kaizen)</td>
<td>An iterative process of seeking the elimination or reduction of non-value adding work embedded in a process. Non-value-added work can be described as elements of work that a customer is unwilling to pay for. They include set-ups, moves, scrap, rework, and process variation.</td>
</tr>
<tr>
<td>Customer Lead Time</td>
<td>The difference in time between when a customer places an order with a supplier and when delivery is expected, i.e. the due date.</td>
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<tr>
<td>Customer Quoted Lead Time</td>
<td>This is the time reported to the customer as necessary to produce the product to the customer specification.</td>
</tr>
<tr>
<td>Cycle Time</td>
<td>The total amount of time required for a worker to complete one cycle of his entire assigned work including manual working time and walking time.</td>
</tr>
<tr>
<td>Daily Customer Requirements</td>
<td>The quantity of products, based on customer orders, planned to be produced in any given day of production. In Flow Manufacturing, the establishment of customer requirements is performed as a daily routine.</td>
</tr>
<tr>
<td>Delivery Frequency (DF)</td>
<td>An interval of time required to replenish supplied materials consumed. Delivery Frequency is a time element used to calculate Kanban quantities in a Flow line.</td>
</tr>
<tr>
<td>Designed Workstation Definition</td>
<td>A description of a physical location and a listing of specific work elements to be performed as defined in the Standard Work Definition. Workstation Definition, work elements, TQM Check Points, and TQM self-checks equals approximately one Takt time.</td>
</tr>
<tr>
<td>Downstream Workstation</td>
<td>The next adjacent workstation that continues the elements of work and TQM Check Points defined in the Standard Work Definition.</td>
</tr>
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<tr>
<td>Effective Work Minutes</td>
<td>A statement of the amount of time available to manufacturing employees to perform work.</td>
</tr>
<tr>
<td>Employee Qualification Board</td>
<td>A display, designed in a matrix format, with the horizontal axis indicating the designated workstations or areas, based on Flow Processing designs, and the vertical axis listing an assigned team of employees. The current certification level of each employee is recorded at the junction of the two points.</td>
</tr>
<tr>
<td>External Changeover</td>
<td>Elements of changeover work that can be performed while the process continues to operate. Changeover work done in parallel to run time.</td>
</tr>
<tr>
<td>Fail-Safe</td>
<td>A process, individual work element, or component that contains no variability. Because of its design, the process, work element or part cannot be produced any way other than the correct way.</td>
</tr>
<tr>
<td>Failsafe Devices (poka yoke)</td>
<td>This refers to the low-cost, highly reliable devices or innovations that either detect abnormal situations before they occur at a production process or, once they occur, will stop the machines or equipment and prevent the production of defective products. 1- Those which prevent errors by an operator, and those which detect errors by an operator and give a warning. 2- Those which detect defects in products and prevent further processing on them.</td>
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<tr>
<td>Five Whys</td>
<td>The 5 Whys is an iterative question-asking technique used to explore the cause-and-effect relationships underlying a particular problem.</td>
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<tr>
<td>Five S</td>
<td>5S is the name of a workplace organization method that uses a list of five Japanese words: seiri, seiton, seiso, seiketsu, and shitsuke. In English we use the terms Sort, Shine, Set-in-Order, Standardize, and Sustain.</td>
</tr>
<tr>
<td>Fixed Quantity Batch Machine</td>
<td>A machine process where the lot size is established by parameters other than actual demand.</td>
</tr>
<tr>
<td>Fixed-Course Pick-Up (Mizusumashi)</td>
<td>In this system, a delivery worker goes around fixed routes from the Parts Supermarket to the production areas delivering sets of parts as signaled by Kanban. Taiichi Ohno coined the phrase as Mizu-Sumashi or Water Strider/Skeeter.</td>
</tr>
<tr>
<td>Flat Level Bill of Materials</td>
<td>A listing of all parts and raw materials that go into a parent assembly showing the quantity of each required to make that assembly. A flat bill of material does not contain sub-assemblies or attempt to define parent assembly product routing. This is also known as “Single-level BOM”.</td>
</tr>
<tr>
<td>Flexible Staffing</td>
<td>The ability to assign the number of trained and certified employees to a Flow Process required to match the actual demand for work on any given day.</td>
</tr>
<tr>
<td>Flexing</td>
<td>The movement of production employees along manufacturing processes to smooth out production flow. In its simplest form flexing refers to the movement of an employee “one up and one down” from his primary workstation based on the signaling by the IPKs and/or workstation.</td>
</tr>
<tr>
<td>Flow Production Planning</td>
<td>The daily process of determining the mix / volume of customer orders and forecast requirements planned for production. The planning steps include Resource Time Availability verification and Kanban material validation.</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>The planned production rate based on scheduled orders.</td>
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<tr>
<td>Flow-Based Response Time</td>
<td>The accumulated work content time along the longest path of the Process Flow Diagram (PFD). Because some work is performed in parallel, work performed in a Flow Process is typically shorter than the total work content time.</td>
</tr>
<tr>
<td>Forecast Volume (FV)</td>
<td>The assumption of future mix and volume. FV is one of the elements in the calculation of Takt time.</td>
</tr>
<tr>
<td>Frequent Conveyance</td>
<td>This refers to increasing the delivery frequency of parts, in order to keep the inventory at each process to a minimum. To do this without lowering the load efficiency of vehicles (i.e., without increasing the total runs made by all vehicles) calls for mixed loading.</td>
</tr>
<tr>
<td>Go and See Problem Solving (Genchi Genbutsu)</td>
<td>Problem solving at the actual place to see what is really going on. Essentially it means to go out and see for yourself and not rely on second or third hand information.</td>
</tr>
<tr>
<td>Graphic Work Instructions</td>
<td>A set of graphical illustrations depicting the work to be performed at a workstation including TQM checkpoints and self-checks. The identified work elements are derived from the Standard Work Definition and are equal to approximately one Takt time.</td>
</tr>
<tr>
<td>Independent Process</td>
<td>A process that is not linked to the downstream consuming process with an IPK signal.</td>
</tr>
<tr>
<td>In-Process Kanban (IPK)</td>
<td>A clear and visible signal placed on the downstream side of a workstation to overcome variability of work time. An IPK also serves as a signal for an employee to flex. An IPK is very rarely identified by a specific part number.</td>
</tr>
<tr>
<td>Internal Changeover</td>
<td>Elements of changeover work that can only be performed while the process is halted. Changeover work that cannot be completed in parallel to run time.</td>
</tr>
<tr>
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<tr>
<td>Kanban</td>
<td>A Japanese word that defines a communication signal or card. It is a technique used to pull products and materials through Flow Processing lines. Kanbans take several forms based on application: in-process, material two-bin, multi-bin, one-time use, and multi-card.</td>
</tr>
<tr>
<td>Kanban Chain</td>
<td>Two or more Kanban Replenishment Links that form the complete replenishment path for a part or an item.</td>
</tr>
<tr>
<td>Kanban Point</td>
<td>A place that a material Kanban is located by design.</td>
</tr>
<tr>
<td>Kanban Replenishment Link (Kanban Link)</td>
<td>Any two Kanban Points that form a “consumed at” and “refilled from” relationship for part or an item.</td>
</tr>
<tr>
<td>Leveled Production (Heijunka)</td>
<td>Is the overall leveling in a production schedule of the variety and volume of items produced in given time periods. This is a prerequisite for Just-In-Time production.</td>
</tr>
<tr>
<td>Line Balancing</td>
<td>The process of refining the workstation definition by applying the balancing tools.</td>
</tr>
<tr>
<td>Material Two Bin Kanban</td>
<td>A material replenishment methodology using two equally-sized containers containing quantities based on the desired replenishment frequency and usage. As the first container is emptied, it becomes the signal for replenishment while the second container continues to supply the point of consumption.</td>
</tr>
<tr>
<td>Mixed Family</td>
<td>A family definition consisting of products grouped together based on commonality of manufacturing processes, standard times, and materials.</td>
</tr>
<tr>
<td><strong>Multiple Signal Card Kanban</strong></td>
<td>A material replenishment technique that uses multiple material Kanban cards as signals to communicate the requirement to replenish materials. Multiple signals are typically used in processes or independent cells where long setup/changeovers and replenishment times are present.</td>
</tr>
<tr>
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</tr>
<tr>
<td><strong>One-time Use Kanban</strong></td>
<td>The signal for material that once consumed is not automatically replenished. The one-time use Kanban is used for highly configured, customized products, or for materials whose usage is very small and continuous replenishment would not be a cost-effective strategy.</td>
</tr>
<tr>
<td><strong>Operational Availability</strong></td>
<td>The time that a machine operates maintenance free as a percentage of the time during which it is switched on. This is equivalent to the reliability of the equipment and its maintenance. The ideal condition is to have 100% operational availability during scheduled work time.</td>
</tr>
<tr>
<td><strong>Output Variance</strong></td>
<td>A measurement of the number of units actually produced compared with the planned number of units for that day.</td>
</tr>
<tr>
<td><strong>Pitch</strong></td>
<td>The frequency of releasing and measuring of units of work.</td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>Sequential tasks of like work performed at constant volume in a given location. A process in manufacturing is a combination of resources (people and machines) that convert material toward the completion of a product. A process has a single Takt time.</td>
</tr>
<tr>
<td><strong>Process Capacity</strong></td>
<td>The highest output rate that can be achieved at a process with the current product specifications, product mix, labor and equipment.</td>
</tr>
<tr>
<td><strong>Process Flow Diagram</strong></td>
<td>A graphic depiction of the processes required, in sequence, to build one unit of product.</td>
</tr>
<tr>
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</tr>
<tr>
<td><strong>Process Matrix</strong></td>
<td>A matrix showing the manufacturing processes identified from the PFDs across the column headings and the products listed down the left-hand column. The Process Matrix is used to determine multi-product families with common processes and standard work times.</td>
</tr>
<tr>
<td><strong>Resource</strong></td>
<td>A person or machine that can carry out work tasks required to manufacture a product.</td>
</tr>
<tr>
<td><strong>Resource Time Available (RTA)</strong></td>
<td>The total resource work minutes available in a day (employees, workstations, and/or machines) to build products.</td>
</tr>
<tr>
<td><strong>Resource Time Required (RTR)</strong></td>
<td>The total resource work minutes required in a day (employees, workstations, and/or machines) to build products.</td>
</tr>
<tr>
<td><strong>Safety Stock Percentage</strong></td>
<td>An estimate of the percentage of over-planning needed to overcome inaccuracies in volume predictions.</td>
</tr>
<tr>
<td><strong>Sequencing</strong></td>
<td>The process of determining the sequence in which the daily production orders will be produced on the Flow Line.</td>
</tr>
<tr>
<td><strong>Sequencing Control Board</strong></td>
<td>A scheduling communication tool, usually a board, which prioritizes the order that products are to be built.</td>
</tr>
<tr>
<td><strong>Sequencing Rules</strong></td>
<td>A series of guidelines developed to optimize the sequence of products to be built in the Flow line.</td>
</tr>
<tr>
<td><strong>Single-Piece Flow Manufacturing</strong></td>
<td>The building and moving of one unit of product at a time through a production process.</td>
</tr>
<tr>
<td><strong>Standard Time Weighted (STw)</strong></td>
<td>The numerator of the resource calculation formula. This is the weighted average, by volume, of the standard work times of all the products produced in a process.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
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<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Standard Work Definition (SWD)</td>
<td>A definition of the required work, materials, standard times, and identified quality criteria to build a product in a specific production process.</td>
</tr>
<tr>
<td>Standardized Work</td>
<td>A precise description of each work activity specifying cycle time, Takt time, the work sequence of specific tasks and the minimum inventory of parts on hand needed to conduct the activity.</td>
</tr>
<tr>
<td>Stores</td>
<td>The physical location where raw and purchased materials are stored for consumption.</td>
</tr>
<tr>
<td>Supermarket</td>
<td>An inventory storage area adjacent to manufacturing processes.</td>
</tr>
<tr>
<td>Supplier Kanban</td>
<td>A Kanban signal for an outside supplier.</td>
</tr>
<tr>
<td>Takt Time</td>
<td>A time volume relationship calculated as the rhythm, beat or cadence for each process of a flow line. Takt is used to establish resource definition and line balance in Flow Processing.</td>
</tr>
<tr>
<td>Toyota Production System (TPS)</td>
<td>The Toyota Production System (TPS) is an integrated system, developed by Toyota, that comprises its management philosophy and practices. TPS is based on two pillars: Just-in-Time manufacturing, and employee engagement (jidoka). Its primary purpose is to maximize value and eliminate waste.</td>
</tr>
<tr>
<td>TQM Check Point</td>
<td>A secondary quality check to validate that an element of work has been performed correctly. The TQM Check Point is the responsibility of the next employee in the Flow Process. If an element of work is found to be defective (failing the TQM Check) the unit of work is passed back to the person upstream who originally performed the work steps.</td>
</tr>
<tr>
<td>TQM Self-check</td>
<td>A quality check that is performed where an element of work contains process variability. The self-check is the responsibility of the employee did the work.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
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</tr>
<tr>
<td>Transport Time</td>
<td>The amount of time required for the physical movement of a product from one workstation, process, or cell to the next.</td>
</tr>
<tr>
<td>Upstream Workstation</td>
<td>The previous adjacent workstation.</td>
</tr>
<tr>
<td>Value Stream</td>
<td>Sequence of processes and other activities required to deliver a unit of product.</td>
</tr>
<tr>
<td>Value Stream Map</td>
<td>A flow chart that depicts the relationship of processes to deliver one unit of product to a customer.</td>
</tr>
<tr>
<td>Visual Control</td>
<td>This refers to means by which managers and supervisors can tell at a glance if production activities are proceeding normally or not.</td>
</tr>
<tr>
<td>Waste</td>
<td>Any activity or element of work that does not change the form, fit, or function of the product, or does not add value in the eyes of the customer, is considered waste.</td>
</tr>
<tr>
<td>Waste of Defects</td>
<td>Work with defects that must be fixed or scrapped.</td>
</tr>
<tr>
<td>Waste of Inventory</td>
<td>All inventory is waste. It may be necessary waste, but waste nonetheless.</td>
</tr>
<tr>
<td>Waste of Motion</td>
<td>The movement of employees that does not add value to the product.</td>
</tr>
<tr>
<td>Waste of Over-processing</td>
<td>Doing more than is necessary to advance the product in a process.</td>
</tr>
<tr>
<td>Waste of Overproduction</td>
<td>Producing more than what is needed for immediate production.</td>
</tr>
<tr>
<td>Waste of Transportation</td>
<td>All transportation is waste. It may be necessary waste, but waste nonetheless.</td>
</tr>
<tr>
<td>Waste of Waiting</td>
<td>Waiting is always waste.</td>
</tr>
<tr>
<td>Working Capital</td>
<td>The current assets necessary to operate the business including raw material, in-process, and finished goods inventories, plus accounts receivable minus accounts payable.</td>
</tr>
<tr>
<td>Workstation</td>
<td>A physical location where standard work is performed.</td>
</tr>
</tbody>
</table>
Index

Symbols
7S 32–42

A
ABC 25–30
Add Additional IPKs 140–142
Adding Resources v–xii, 128–142, 130–142, 133–142
Add Overflow Workstations 140–142
Agile Manufacturing 21–30
Assembly Line Manufacturing 21–30
Available Work Minutes 182–190

B
Backflush 25–30, 203, 203–214
212–214
Balancing Tools 204, 204–214
batch and queue 21–30, 125–142, 134–142
Batch Machine 119–124, 207, 207–214
batch production 193–196, 194–196
Building a Lean Culture 174–176
Business Systems Audit 33–42

C
186–190
capital asset utilization 20–30
castle wall 47–56
Cellular Manufacturing 21–30, 193–196
Certification 63–68, 184–190, 187–190, 189–190, 204, 204–214
Certified Supplier 204, 204–214
CFM 21–30
Changeover Matrix 204, 204–214
Conceptual Layout vi–xii, 184–190, 185–190
conceptual line design 118–124, 122–124, 174–176, 184–190
Configuration Traveler 204, 204–214
constant volume 58–68
Continuous Flow Manufacturing 21–30
Continuous Flow Process 204, 204–214
continuous process improvement 23–30, 85–94, 103–116, 188–190, 305–214
Conveyance 208
Cost To Carry Inventory 199–202
CPI 183–190, 188–190, 190
critical path work-content time 24–30
Current State 49–56
Current State Value Stream Map 45–56, 47–56, 49–56, 179–190
Customer Lead-time 24–30, 205–214
cycle counting 32–42

D

Daily Customer Requirements 205, 205–214
Defects 213
Defects and Errors 129–142
Delivery Frequency 205, 205–214, 205–214
demand-driven production 82–94
Deming Quality Award 194–196
DEPLOYMENT PLAN 178–190, 187–190
Designed Workstation Definition 205
designing pull system 36–42
DF 205–214
direct connect 144–158, 145–158
Dollars Per Day 198–202
Dollars Per Labor Hour 199–202
Downstream Workstation 205

E

Eli Goldratt 195–196
Eliminating Waste v–xii, 128–142
employee involvement systems 36–42
Employee Qualification Board 206, 206–214
Engagement 39–42, 40–42
equipment up-time 23–30
Error-Proofing 175–176
Establish Bin Sizes 137–142
External Changeover 206, 206–214

F

Fail-Safe 206, 206–214
Family 209
feeder lines 24–30, 52–56, 140–142
FGI 199–202
FIFO Lane 147–158, 149–158
Five S 207, 207–214
Five Whys 206, 206–214
Fixed-Course Pick-Up 207, 207–214
Flexible Staffing 207–214
Flexing 207, 207–214
Floor space 20–30, 71–80
Flow and Pull 39–42, 40–42
Flow-Based Response Time 208–214
Flow lines 122–124, 125–142, 165–172
Flow Production Planning 207–214
Forecast Volume 208, 208–214
Frank Gilbreth 191–196
Frederick Winslow Taylor 14–18, 104–116, 191–196
Frequent Conveyance 208–214
Future State Value Stream Maps 184–190

G

gemba 36–42
Genchi Genbutsu 208, 208–214
Go and See 208, 208–214
Graphic Work Instructions 183–190, 208, 208–214

H

Heijunka 209, 209–214
Henry Ford 14–18, 191–196
High visual impact 54–56

I

Identify Bottlenecks 167–172
Implementation Leader Training 36–42
improved housekeeping 53–56
Improved productivity 15–18, 20–30
Inappropriate Processing 129–142
Increased Productivity 22–30
Independent Process 208, 208–214
162–172, 204–214
Input 97–102, 98–102, 153–158
Internal Changeover 208, 208–214
Inventory Accuracy vii–xii, 32–42, 201–202
Inventory Plus Time v–xii, 131–142
Inventory reduction 19–30, 23–30
208–214, 208–214

J

Japanese Industrial Miracle 194–196
JIT 21–30
Joseph Juran 194–196
Just-in-Time 21–30, 212, 212–214

K

189–190, 190, 194–196, 200–202, 205, 205–214
Kaizen Burst 45–56, 49–56, 51–56
Kaizen Event 175–176
Index 219


Kanban Chain 209, 209–214

Kanban Link 209

Kanban Point 209

Key Performance Metrics 34–42

Kiichiro Toyoda 192–196

Kitting 70–80

L

Labor conversion time 110–116

Labor setup time 110–116

Law of Diminishing Returns 147–158, 165–172

Layout Plan 185–190, 186–190

leadership team 14–18, 35–42, 36–42, 37–42, 64–68


Lead Time 205–214

Lean Audit 178–190, 189–190, 190

Lean-Certified 190

Lean Enterprise 33–42, 34–42, 35–42, 37–42


Lean Master Plan 3–xii, 35–42, 55–56


Lean Seven Wastes 96–102

Level Production 209

Line Balancing 96–102, 188–190, 209, 209–214

Line Consumption Factor 109–116


Line Live 178–190, 189–190

Line Throughput and Balance 166–172

Linked Processes 39–42

linking and balancing 16, 16–18

Long-Range Capacity Planning 169–172

Low Risk 53–56
M

Machine run attended time 110–116
Machine run time 110–116
Machine run unattended time 110–116
Machine setup attended time 110–116
Machine setup time 109–116
Machine setup unattended time 110–116
Main Path 184–190
Malcolm Baldrige 41–42
Malcolm Gladwell 176
Management Buy-In 170–172
Management Leadership Training 35–42
Material Delivery System 174–176
material management 27–30, 36–42, 124, 198–202
Memory Jogger vi–xii, 173–176, 175–176, 176
Michael Schrage 159–172, 161–172, 163–172
Mike Rother 174–176
Mission and Vision Statement 34–42
Mistake-proofing 106–116
Mixed Family 209, 209–214
Mixed-model lines 70–80
mixed-model production 78–80
Mizusumashi 207, 207–214
monuments 155–158
Motion 213
Move Option Work Into Feeder Lines 140–142
MRP system 34–42, 47–56, 204–214
muda 129–142
Multiple Signal Card Kanban 210
multi-product flow line 52–56, 70–80

N

Number of Changeovers Possible 136–142
Number of Replenishment Bins 137–142
NVA 113–116, 128–142, 189–190

O

O.E.E. 55–56
One Best Way 104–116
one-piece-flow 193–196, 194–196, 204–214
One-time Use Kanban 210
operating cost reductions 22–30
Operational Availability 210, 210–214
operator movement 140–142, 173–176
optimized floor space 173–176
Optional Process Modifier 102
Outliers 176
Output 97–102, 98–102, 210–214
output rate 22–30, 210–214
Output Variance 210, 210–214
Overall Equipment Effectiveness 55–56
Overhead Costs 23–30
Over-processing 213
Overproduction 129–142, 213, 213–214

P

Paired Overlapping Loops of Cards with Authorization 141–142
parts lists 183–190, 187–190
Physical Line Implementation 174–176
Pitch 210, 210–214
Plan For Every Part 52–56
poka yoke 206, 206–214
Poka Yoke 106–116
POLCA v–xii, 141–142, 142
PowerPoint 63–68
Preliminary Product Families 44–56
Preventive Maintenance vii–xii, 202
problem-solving 37–42
Process Capacity 210, 210–214
processing rate 22–30
process throughput 60–68, 84–94, 99–102, 100–102, 101–102
Production Planning 207
Production Plan Validation 168–172
Productivity Assessment 169–172
Project Management 37–42
Promote Operator Movement 140–142

Q

quality criteria 105–116, 111–116, 204–214, 212–214
quantifiable benefits 53–56
Quantity Consumed iv–xii, 97–102, 102, 149–158
quick changeovers 78–80
Quick Response Manufacturing 21–30, 141–142

R

Rapid Improvement 23–30, 115–116
Rapid Improvement Events 23–30
reduced floor space 53–56, 141–142, 144–158
reduced inventory 53–56
reduced scrap and rework 53–56
Reduction in the working capital 20–30
Repetitive Manufacturing 21–30
repetitive motion injuries 106–116
Resource Time Available 211
Resource Time Required 211
Response Time Measurement 166–172

S

Safety Stock Percentage 211, 211–214
Self-Assessment questionnaire 190
Self Balancing Line 77–80, 138–142, 139–142, 142
self-check 111–116, 212–214
Sequence Product Mix Strictly 140–142
Sequencing Control Board  211, 211–214
Sequencing Rules  169–172, 211, 211–214
Serious Play: How The World’s Best Companies Simulate to Innovate  159–172
Seven Wastes of the Toyota Production System  129–142
Shigeo Shingo  193–196
Shop Floor Control  34–42
Shop Management and the Principals of Scientific Management  193–196
shortened customer lead-times  22–30
simulation modeling  x-xii, 159–172
Six Sigma  14–18, 16–18, 32–42, 35–42, 53–56, 112–116
Sizing In-Process Inventory Buffers  166–172
Software Tools  63–68
Staffing  170–172, 207, 207–214
Standardized Work  212, 212–214
Standard Times  111–116
Standard Time Weighted  211–214
Standard Weighted Time  211
Start-up Strategy  187–190
Stores  212, 212–214
STW  120–124, 211, 211–214
Supermarkets  62–68
Supplier Kanban  212, 212–214
sustainability  x–xii, 37–42, 63–68, 64–68, 189–190, 195-196

Sustained Performance  40–42

T


Takt Times 22–30

Target Volume 95–102, 97–102, 164–172, 165–172

Taylorism 104–116

The Goal 195–196

Theory of Constraints 54–56, 195–196


Throughput Volume 98–102, 102

time line 44–56, 47–56

Time Plus Inventory 128–142, 133–142

Total Number of Supermarket Bins 137–142

Total Productive Maintenance 23–30

Total Quality Management 23–30

Total Run Time Required 136–142

Toyota Kata 174–176

Toyota Motor Company 192–196, 193–196


TPM 23–30

TPS 21–30, 212, 212–214, 212–214


TQM Check Point 212

TQM Self-check 212


Training Plan 187–190

Transportation 129–142, 213, 213–214

Transport Time 213, 213–214

Two Bin Kanban 209, 209–214

U

unique processes 59–68

Units Per Labor Hour 199–202

Unnecessary Inventory 129–142

Unnecessary Motion 129–142

Upstream Workstation 213
Index

V

Valid Customer Delivery Dates 168–172
Value Stream 2–xii, x–xii, xi–xii, 13–18, 14–18, 15–18, 16–18, 21–30, 36–42, 37–42, 39–42,
213–214, 213–214
Visio 63–68
Visual Aids 182–190
Visual Control 213, 213–214
visual factory 33–42, 36–42, 188–190
visual tools 173–176

W

Wait time 21–30
warranty costs 23–30
W. A. Shewhart 194–196
213–214
W. Edwards Deming 35–42, 194–196
146–158, 198–202
Workforce Training 36–42
Working Capital 213, 213–214
213–214
Workstation Definition 143–158, 152–158, 153–158, 183–190, 205–214
workstation definitions 107–116
180–190, 181–190, 183–190, 212–214