Framework for a Lean Manufacturing Planning System

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ABSTRACT
This paper presents a planning system for Lean Manufacturing and is applicable to a variety of manual and automated manufacturing operations. By defining a standard set of Lean Manufacturing metrics, our research sets up a framework for performance measurement and benchmarking. A financial *Cost of Waste* measure is developed from data on current performance levels, and the planning framework develops a Lean Scorecard that establishes the gap of current performance from desired stretch performance targets, to facilitate planning for closure of the performance gap. For planning, users select one or more of 14 standard Lean Manufacturing strategies ranging from Kanban or Pull systems, to manufacturing cells. Each strategy can be implemented at a basic or comprehensive level. In addition, projected performance improvements are used to estimate the performance improvements for each of the metrics. Finally, a Lean Manufacturing Cash Flow summary is developed to show Cost of Waste, Cost of Lean Implementation, and Lean Savings over a five-year period. Together, these cash flows make it possible to compute a Return on Investment (ROI) evaluation of the Lean Manufacturing expenditures.

KEYWORDS
LEAN MANUFACTURING; PERFORMANCE METRICS; PERFORMANCE ASSESSMENT; BENCHMARKS; COST OF WASTE; LEAN SCORECARD.

BIOGRAPHICAL NOTES:
Dr. Mejabi is an Asscociate Professor of Industrial and Manufacturing Engineering at Wayne State University and President of Simplex Systems, Inc., an Engineering and Management Consulting firm. Dr. Mejabi earned his doctorate degree from Lehigh University in 1988. Since that date he has researched, taught, mentored, and consulted on all aspects of Process Management, Lean Manufacturing, and Continuous Improvement with numerous students and companies and from all five continents of the world.

INTRODUCTION
Lean Manufacturing has recently become pervasive as the primary strategy for manufacturing performance enhancement. Many companies now realize that business success in the short, medium and long term is predicated upon outstanding performance in the quality of products and efficiency of manufacturing operations. These companies recognize that consistent and disciplined application of Lean Manufacturing strategies,

with the emphasis on waste elimination and process streamlining, can offer a steady path towards business excellence.

Lean Manufacturing has its origins in the Toyota Production System [Ohno 1988] and its explicit emphasis is on the elimination and reduction of waste. The seven wastes are defined generically to include: overproduction, waiting, transportation, inappropriate processing, excessive inventory, excessive motion, and product quality defects.

Over the years, Lean Manufacturing has developed into a core strategy and focus for continuous improvement. Process Management and tools such as process simulation have also been recognized as the implementation mechanisms for Lean Manufacturing [Czarnecki et al. 2000]. In most cases, however, companies have followed an ad-hoc approach to planning and then implementing their Lean Manufacturing strategies and so despite their good intentions, they have only experienced mixed results. This issue suggests a need for research to develop a standardized and systematic approach for planning and implementation of Lean Manufacturing. Research has currently gone a long way to offering structured methods such as axiomatic design for analysis of Lean Manufacturing systems [Reynal and Cochran 1996], and these provide building blocks for a Lean Manufacturing planning framework. In order to provide a standard methodology for Lean Manufacturing planning, our research has developed a framework and planning tool that helps companies plan their Lean Manufacturing implementations in a more consistent and systematic fashion.

The Lean Manufacturing planning framework is based on a seven-step process starting with an assessment and data collection for measuring performance levels of Lean Manufacturing metrics. The framework then estimates the Cost of Waste through an analysis of the quantifiable metrics for developing a Lean Scorecard. In order to improve performance through implementation of Lean Manufacturing, planners can select from among the standard Lean Manufacturing strategies and establish an implementation timeline over a five-year period. Implementation budgets are then established based on the particular Lean Initiatives to be implemented either on a *basic* or *comprehensive* level. In addition, expected improvements for the Lean Metrics are estimated based on the scale of the planned Lean implementation. Finally, a financial analysis is used to correlate the Cost of Waste, Cost of Lean, and Lean Savings, into a Cash Flow and Return on Investment (ROI) summary for justifying the cost of the Lean Manufacturing implementation.

Case Study Introduction

Our framework for a Lean Manufacturing planning system is illustrated by using a case study of Thypin Company, a medium-sized manufacturing company in the automotive industry. Thypin has recently initiated a Lean Manufacturing program and our research collaboration involved a pilot program of the Lean Manufacturing planning template that is described in this paper.

LEAN METRICS

In order to provide a standard set of metrics that offer a set of performance measures for Lean Manufacturing, our research has defined 17 metrics organized into four categories of: Process Flow, Quality, Financial measures, and Productivity. The metrics, as well as their units of measure, metric orientation (lower is better [↓] or higher is better [↑]), and definitions are shown in Table 1 below.

Table 1: Lean Manufacturing Metrics

	Performance Metric		Unit of Measure	Definition
PROCESS FLOW METRICS				
1	Process Throughput	PT	Jobs per Hour ↑	Process output rate per hour of sellable product.
2	Line Efficiency	LE	Percent (%) ↑	Ratio of actual process Throughput to the theoretical ideal throughput based on the *pace* and cycle time at the bottleneck station.
3	Total Manufacturing Leadtime	TML	Hours ↓	Total time from receipt of raw material to shipping of the final product.
4	Processing time quotient	PTQ	Percent (%) ↑	Ratio of value added processing time to total manufacturing leadtime (TML).
5	Material Handling time quotient	MHTQ	Percent (%) ↓	Ratio of material handling time to total manufacturing leadtime (TML).
6	Setup Time quotient	STQ	Percent (%) ↓	Ratio of setup time to total manufacturing leadtime (TML).
7	Equipment & Personnel Waiting time quotient	EPWQ	Percent (%) ↓	Ratio of equipment and personnel queuing and waiting time to total manufacturing leadtime (TML).
8	Materials Waiting Time quotient	MWTQ	Percent (%) ↓	Ratio of waiting time for materials to total manufacturing leadtime (TML).
9	Information Waiting Time quotient	IWTQ	Percent (%) ↓	Ratio of waiting time for information to total manufacturing leadtime (TML).
QUALITY METRICS				
10	Scrap Rate	SR	Percent (%) ↓	Percentage of units starting as raw material that are lost as scrap from all steps in the process.
11	Rework Rate	RR	Percent (%) ↓	Percentage of units starting as raw material that have to be reworked at least once in the process.
FINANCIAL METRICS				
12	Cost per Part	CPP	$/Unit ↓	Total cost per unit for raw materials, processing and indirect overhead.
13	Inventory Level	IL	Units ↓	Inventory level of raw materials, work in process and finished goods.
14	Inventory Cost	IC	$/Month ↓	Holding cost per month for raw material, work in process and finished goods inventory.

PRODUCTIVITY METRICS				
15	Labor Productivity	LP	Percent (%)	Ratio of monthly product value shipped to monthly labor expenditures.
16	Capital Productivity	CP	Percent (%)	Ratio of monthly product value shipped to monthly capital charges [for tools, equipment and facilities] depreciation and direct expenditures.
17	Setup Intensity	SI	Percent (%)	Ratio of setup time to scheduled plant operating time.

PERFORMANCE ASSESSMENT

Data collection and an initial state assessment form the foundation of the Lean Manufacturing planning framework. Data that is collected covers a range of attributes of the current manufacturing operations, ranging from Throughput rates to a high-level map of the manufacturing process. Figure 1 below uses the Thypin Co. case study to illustrate the data input requirements of the planning framework.

Thypin Co. Lean Manufacturing Data Collection Template			
Q 1 :	Throughput Rate (Jobs per Hour)	55	JPH
Q 2 :	Average Monthly Production	10,000	Units
Q 3 :	Average Level of WIP	1,667	Units
Q 4 :	Average Inventory Holding Cost ($/month)	20	$/Unit per Month
Q 5 :	Scrap Rate	5	Percent (%)
Q 6 :	Rework Rate	10	Percent (%)
Q 7 :	Average Cost per Part	50	$/Unit
Q 8 :	Average Value (selling price) per unit of finished products	70	$/Unit
Q 9 :	Floor Space available	40,000	Sq. Ft.
Q 10 :	Monthly Labor Expenditure	300,000	$/Month
Q 11 :	Monthly Capital Overhead [Equipment & Facilities] Depreciation & Expenditure	450,000	$/Month
Q 12 :	Average Manufacturing Leadtime	5	Hours
Q 13 :	Manufacturing Leadtime Breakdown (*sum to 100%*)		
Q 14 :	% **Value-added processing** time	60	Percent (%)
Q 15 :	% **Necessary Non Value-added material handling** time	10	Percent (%)
Q 16 :	% **Necessary Non Value-added setup** time	10	Percent (%)
Q 17 :	% **Unnecassary Non Value-added waiting** time for equipment & personnel downtime	10	Percent (%)
Q 18 :	% **Unnecassary Non Value-added waiting** time for materials	5	Percent (%)
Q 19 :	% **Unnecassary Non Value-added waiting** time for information	5	Percent (%)
Q 20 :	Line setup frequency (average number of setup changes per week)	10	Changes/Week
Q 21 :	Operating Schedule	6	Shifts/Week
Q 22 :	Shifts Duration	8	Hours/Shift

Q 23 : Process Map	Operation Name	Cycle Time (secs.)	+/- Variability (%)
Operation-1	Op-1	45	5
Operation-2	Op-2	60	5
Operation-3	Op-3	45	5
Operation-4	Op-4	55	5
Operation-5	Op-5	50	5
Operation-6	Op-6	40	5
Operation-7	Op-7	55	5
Operation-8	Op-8	50	5
Operation-9	Op-9	45	5
Operation-10	Op-10	45	5
Operation-11	Op-11	55	5

Figure 1: Data Collection Template

The next step in the performance assessment is reporting of the results of the current status of manufacturing operations. Reporting highlights several measures such as the process TAKT Time (cycle time at the bottleneck workstation), ideal process

Throughput, actual process Throughput, total manufacturing leadtime and broken down by leadtime component, Scrap Rate (%), Rework Rate (%), Cost per Part, Average Inventory Level, Monthly Inventory Cost, Labor Productivity, Capital Productivity, Line Efficiency, and Setup Intensity.

The framework also facilitates benchmarking of similar manufacturing operations in order to offer an inspiration and learning opportunity for the Lean Manufacturing implementation. At the same time, by reviewing the current process status and benchmark performance, stretch targets for each metric can be established. Figure 2 shows the performance targets template for our case study with values shown for the initial status, benchmark performance, and stretch targets. In the spirit of Lean Manufacturing, performance targets are required to be specified as stretch values to be achieved over a maximum of five years.

Thypin Co. Lean Manufacturing Performance Targets					
		Current Value	Benchmark Performance	Stretch Target	
# 1 :	Number of Operations	11			
# 2 :	Process Bottleneck Operation	Op-2			
# 3 :	Process TAKT Time	60			Seconds
# 4 :	Ideal Process Throughput	60			Jobs per Hour
# 5 :	Process Throughput	55	80	85	Jobs per Hour
# 6 :	Line Efficiency	91.67	98.00	98.00	Percent (%)
# 7 :	Average Manufacturing Leadtime	5.00	4.00	3.50	Hours
# 8 :	% Value-added processing time	60.00	75.00	85.00	Percent (%)
# 9 :	% Necessary Non Value-added material handling time	10.00	8.00	7.00	Percent (%)
# 10 :	% Necessary Non Value-added setup time	10.00	8.00	8.00	Percent (%)
# 11 :	% Unnecassary Non Value-added waiting time for equipment & personnel de	10.00	3.00	0.00	Percent (%)
# 12 :	% Unnecassary Non Value-added waiting time for materials	5.00	3.00	0.00	Percent (%)
# 13 :	% Unnecassary Non Value-added waiting time for information	5.00	3.00	0.00	Percent (%)
# 14 :	Scrap Rate	5.00	2.00	1.00	Percent (%)
# 15 :	Rework Rate	10.00	7.00	2.00	Percent (%)
# 16 :	Cost per Part	50.00	40.00	30.00	$/Unit
# 17 :	Average Inventory Level	1667	500	400	Units
# 18 :	Monthly Inventory Cost	33333.33	20000.00	10000.00	$/Month
# 19 :	Labor Productivity	233.33	250.00	300.00	Percent (%)
# 20 :	Capital Productivity	155.56	200.00	250.00	Percent (%)
# 21 :	Setup Intensity	10.42	5.00	5.00	Percent (%)

Figure 2: Performance Reporting, Benchmarking and Stretch Target Setting Template

Cost of Waste Computation

Cost of Waste (COW) is a convenient tool, developed as part of the Lean Manufacturing planning framework, for putting a value on the amount of waste from a process. With the focus on waste elimination in Lean Manufacturing, it is necessary to establish a quantitative cost basis for evaluating the magnitude of waste associated with specified manufacturing operations. COW focuses on quantitative sources of waste, such as waste due to scrap, and does not include difficult-to-quantify items such as poor training; thus

COW is actually a conservative estimate of waste that offers a standard yardstick for analyzing different manufacturing plants.

The COW measure in the Lean Manufacturing planning framework considers six quantitative sources of waste cost that include:

- Scrap
- Rework
- Inventory
- Labor Productivity
- Capital Productivity
- Process Inefficiency

Each of the COW line items are computed as follows:

1. <u>Scrap</u>

S = Current Scrap Rate value
Q = Scrap Cost Quotient or cost of scrap as a percentage of the value of finished products
V = Average value of finished products [$]
P = Average monthly volume of production [units]

Thus, the Monthly Cost of Waste from Scrap (COW_S) = S x Q x V x P

2. <u>Rework</u>

R = Current Rework Rate value
Q = Rework Cost Quotient or cost of rework as a percentage of the value of finished products
V = Average value of finished products [$]
P = Average monthly volume of production [units]

Thus, the Monthly Cost of Waste from Rework (COW_R) = R x Q x V x P

3. <u>Inventory</u>

I = Average Inventory Level value
H = Average monthly inventory holding cost per unit [$]

Thus, the Monthly Cost of Waste from Inventory (COW_I) = I x H

4. <u>Labor Productivity</u>

X = Current Labor Productivity level [%]
L = Average monthly labor expenditure [$]
D = Benchmark Labor Productivity level [%]

Thus, the Monthly Cost of Waste from Labor Productivity (COW_L) = $L\left(1-\frac{X}{D}\right)$

5. **Capital Productivity**
Y = Current Capital Productivity level [%]
C = Average monthly capital expenditure [$]
E = Benchmark Capital Productivity level [%]

Thus, the Monthly Cost of Waste from Capital Productivity (COW_C) = $C\left(1-\frac{Y}{E}\right)$

6. **Process Inefficiency**
T = Current Throughput level [Jobs per Hour]
K = Ideal Throughput level [Jobs per Hour]
V = Average value of finished products [$]
O = Operating hours per month [hours]

Thus, the Monthly Cost of Waste from Process Inefficiency (COW_P) =
$V \times O(K-T)$

Figure 3 below shows the results of the Cost of Waste computation for the Thypin Co. case study.

Thypin Co. Lean Manufacturing Performance Scorecard							
Cost of Waste							
Cost Item	Metric Value		Cost Basis			Monthly Cost ($)	Annual Cost ($)
Scrap	5	Percent (%)	100	Percent (%)	Cost of scrap as a % of cost/part	25,000	300,000
Rework	10	Percent (%)	60	Percent (%)	Cost of rework as a % of cost/part	30,000	360,000
Inventory	1667	Units	20	Dollars ($)	Inventory holding cost per unit per month	33,333	400,000
Labor Productivity	233	Percent (%)	1,200	Dollars ($)	Cost per percentage productivity loss	20,000	240,000
Capital Productivity	156	Percent (%)	2,250	Dollars ($)	Cost per percentage productivity loss	100,000	1,200,000
Process Inefficiency	92	Percent (%)	42	Dollars ($)	Cost per percentage of throughput loss	67,200	806,400
					TOTAL COST OF WASTE	$ 275,533	$ 3,306,400

Figure 3: Cost of Waste computation

Lean Manufacturing Scorecard

The performance assessment for each of the 17 Lean Manufacturing metrics is organized into a Lean Manufacturing Scorecard by establishing a 0 to 5 scale. Each metric has a best to worst case benchmarking range, and the current performance value is mapped to the 0 to 5 scale by normalizing the value within the benchmarking range. Normalization involves two steps: (a) mapping to the 0-5 scale, and (b) reconstituting all metrics to a neutral higher is better metric sense. The scorecard is presented as a Poor-Fair-Acceptable-Good-Excellent rating, a spider chart, and an overall Lean Performance Rating Score. The rating is based on the standardized intervals of:

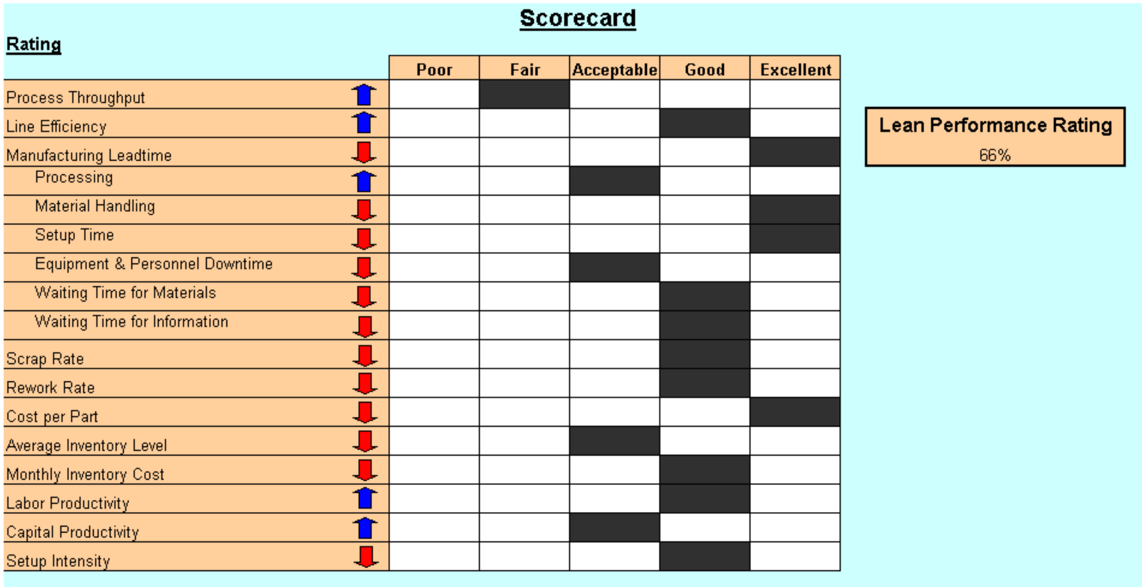
Scale Range		**Rating**
[0.00 to 0.99]	→	Poor

[1.00 to 1.99] → Fair
[2.00 to 2.99] → Acceptable
[3.00 to 4.49] → Good
[4.50 to 5.00] → Excellent

Figure 4 shows the scorecard rating for the Thypin Co. case study. A one percentile range is associated with each of the Poor, Fair and Acceptable ranges, one-and-a-half percentile to Good, and half a percentile to the truly outstanding performance of Excellent. The overall Lean Performance Rating score is a weighted average of scores from the different metrics. Weights for the weighted averaging are shown in Table 2 below. The scores sum to 100% and reflect relative importance of these metrics from surveys of numerous companies participating in our research.

Table 2: Relative Importance Weights for Overall Lean Performance Rating

Performance Metric		**Relative Weight**
PT --	Process Throughput	15 %
LE --	Line Efficiency	10 %
TML --	Total Manufacturing Leadtime	3 %
PTQ --	Processing time quotient	1 %
MHTQ --	Material Handling time quotient	1 %
STQ --	Setup Time quotient	1 %
EPWQ --	Equipment & Personnel Waiting Time quotient	1 %
MWTQ --	Materials Waiting Time quotient	1 %
IWTQ --	Information Waiting Time quotient	1 %
SR --	Scrap Rate	10 %
RR --	Rework Rate	8 %
CPP --	Cost per Part	15 %
IL --	Inventory Level	7 %
IC --	Inventory Cost	9 %
LP --	Labor Productivity	7 %
CP --	Capital Productivity	8 %
SI --	Setup Intensity	2 %



Scorecard

Rating

		Poor	Fair	Acceptable	Good	Excellent
Process Throughput	↑		■			
Line Efficiency	↑				■	
Manufacturing Leadtime	↓					■
Processing	↑			■		
Material Handling	↓					■
Setup Time	↓					■
Equipment & Personnel Downtime	↓			■		
Waiting Time for Materials	↓				■	
Waiting Time for Information	↓				■	
Scrap Rate	↓				■	
Rework Rate	↓				■	
Cost per Part	↓					■
Average Inventory Level	↓			■		
Monthly Inventory Cost	↓				■	
Labor Productivity	↑				■	
Capital Productivity	↑			■		
Setup Intensity	↓				■	

Lean Performance Rating
66%

Figure 4: Lean Manufacturing Scorecard Rating

The scorecard results are also presented in the form of a spider chart. Figure 5 shows the Lean Manufacturing scorecard spider chart for the Thypin Co. case study.

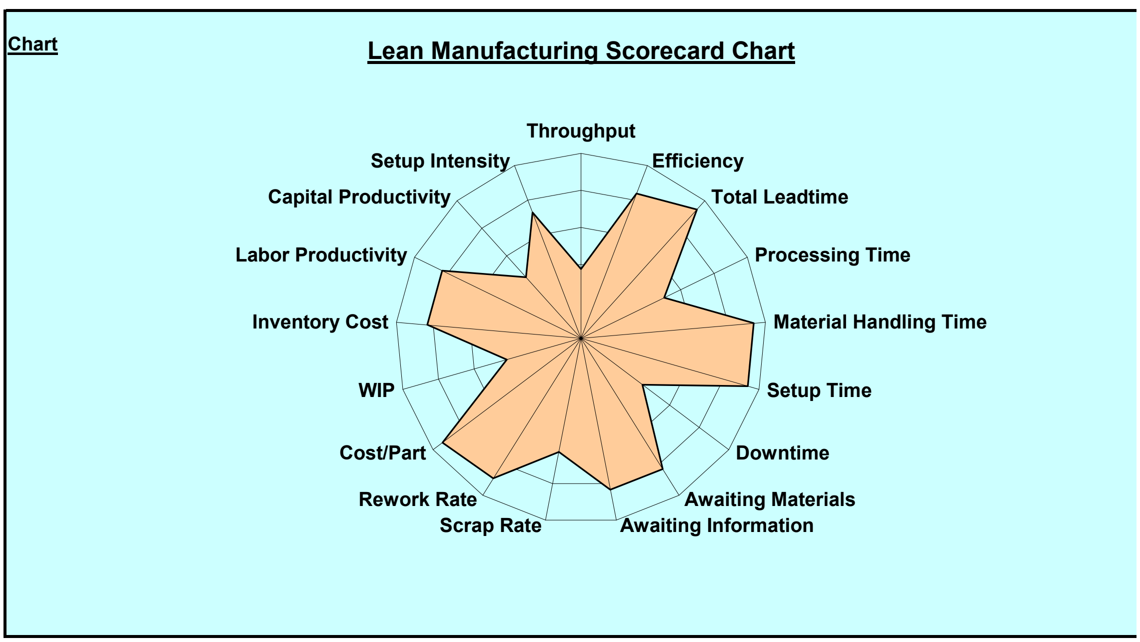


Figure 5: Lean Manufacturing Scorecard Spider Chart

LEAN INITIATIVES

Planning to improve manufacturing performance involves implementation of one or more Lean Manufacturing initiatives with the objective that each Lean Manufacturing initiative that is implemented will contribute performance improvement to a greater or lesser degree for each of the 17 Lean Manufacturing metrics.

In the Lean Manufacturing planning framework, the Basic Lean strategy (program of regular continuous improvement activities with 5S, Spaghetti chart, value stream mapping, and visual management) plus 13 other Lean Manufacturing initiatives have been organized in a menu so that one or more can be selected and scheduled for implementation over a five-year time horizon. Table 3 below lists the Lean Manufacturing initiatives with explanations of each one.

Table 3: Lean Manufacturing Initiatives

	Strategy	Definition
1	Basic Lean	The collection of activities required for a regular continuous improvement program. These include continuous improvement kaizen activities, 5S, spaghetti charting, value stream mapping, and visual management.
2	Error Proofing	The study of common sources of process errors and redesign of the product, process, or tooling to preclude any possibility of such errors. Also known as Poke Yoke.
3	Skills Training Matrix	Tabulation of the primary skills required for quality outcomes in a process, and rating of operators according to their competencies in each area. Training is provided, as needed, to enhance operator's skills and increase the level of cross training.
4	Streamlined Flow	Evaluation of process operations and classifying them into categories of: value added, non value-added necessary, and non value-added unnecessary, in order eliminate or minimize non value-added time.
5	Single-piece flow	Analysis of process flows to minimize batch processing and ensure fast responses to process control problems, minimization of work-in-process, and short production leadtimes.
6	Visual Status Displays	Simple and highly graphical communication of key process status attributes to provide an intuitive understanding of inner workings of the process and ensure quick adaptations to both foreseen and unforeseen process changes. Also known as ANDON Systems.
7	Preventive Maintenance program	Monitoring and disciplined maintenance of key manufacturing equipment and tools to minimize tool and equipment downtimes as well as tooling/equipment induced quality defects.
8	Line Balancing	Analysis and reorganization of process operations and operator assignments (man assignment) to ensure the most balanced workload (cycle time) among process workstations in a manner that is compatible with precedence and other manufacturing constraints, in order to maximize process efficiency.

9	Quick Changeover	Analysis of setup activities and redesign of process steps, products, tooling and equipment, to eliminate or minimize part waiting time associated with setups. Also known as Single Minute Exchange of Dies – SMED.
10	Information Flow Management System	Streamlining and possible automation of all information flows such as product quality data, material and tool availability, process status data, operator data, and work instructions, associated with production and production support. The objective is to eliminate waiting times for information and avoid process errors due to communication of erroneous data.
11	Performance Management System	A closed loop performance control system with tracking of metrics, reporting of the performance status, identification of performance gaps (relative to targets), plus development of improvement plans and implementation follow-up for continuous improvement activities.
12	Pull System	Demand-driven control of process flow to ensure that work-in-process is never permitted to pile up in the process. This strategy facilitates minimization of waste due to inventory holding and helps simplify production planning and control. Also known as a Kanban system.
13	Self Directed Work Teams	Organization of process personnel into sets of autonomous teams with appropriate team governance, team rewards, and team accountability for results.
14	Manufacturing Cells	Organization of products, processes, personnel, and equipment into self contained product-focused cells that emphasize decentralization and flexibility.

Lean Manufacturing Budgeting System

Implementation of each selected Lean Manufacturing initiative will require a budget for detailed design, personnel training, development of support technologies, as well as total system maintenance and upkeep. For example, implementation of a Lean Manufacturing Information Flow Management System requires certain expenditures for design configuration of the system, training of all users, and purchase of hardware and software. The Lean Manufacturing planning framework develops a rough budget estimate for implementation of each selected initiative with cost estimates derived from a cost database based on size of company, manufacturing sub-category, scale of manufacturing operations, complexity of manufacturing operations, geographical region, and extent of implementation (basic or comprehensive). Figure 6 shows the Lean Manufacturing budget for the Thypin Co. case study presented in a project management summary report. The report shows each selected Lean Manufacturing initiative, implementation project start and stop dates, and estimated budget.

Thypin Co. Lean Manufacturing Improvements					
For each, You need the Philosohpy, Process, Tools, Application Know-how, and Human Infrastructure.					
Lean Initiatives Summary					
INITIATIVE	LEVEL	PROJECT			BUDGET
		Starts	Stops	Duration	(per year of implementation)
Basic Lean (regular CI program with 5S, value stream mapping, etc.)	Comprehensive	Dec-01	Ongoing	5 yr(s)	$ 20,000
Error Proofing (Poke Yoke)	Basic	Jun-02	Ongoing	4.5 yr(s)	$ 10,000
Skills Training Matrix	Comprehensive	Jun-04	Ongoing	3.5 yr(s)	$ 30,000
Streamlined Flow (ellimination of non value-added time)	Comprehensive	Dec-03	Ongoing	4 yr(s)	$ 40,000
Single-piece flow	Comprehensive	Dec-03	Ongoing	4 yr(s)	$ 40,000
Visual Status Displays (ANDON System)	Basic	Dec-05	Ongoing	3 yr(s)	$ 20,000
Preventive Maintenance program	Basic	Jun-02	Ongoing	4.5 yr(s)	$ 20,000
Line Balancing	Comprehensive	Dec-01	Ongoing	5 yr(s)	$ 40,000
Quick Changeover (Single Minute Exchange of Dies -SMED)	None	--	--	--	--
Comprehensive Information Flow Management System	Basic	Dec-07	Ongoing	2 yr(s)	$ 60,000
Comprehensive Performance Management System	Comprehensive	Dec-01	Ongoing	5 yr(s)	$ 80,000
Pull System (Kanban)	Basic	Jun-04	Ongoing	3.5 yr(s)	$ 40,000
Self Directed Work Teams	Comprehensive	Dec-07	Ongoing	2 yr(s)	$ 170,000
Manufacturing Cells	None	--	--	--	--
		Total Annual Budget:			$ 570,000

Figure 6: Lean Manufacturing Budget and Project Management Summary

Projecting Lean Manufacturing Performance Improvements

Inasmuch as it is impossible to predict exactly how Lean Manufacturing metrics will improve due to implementation of Lean Manufacturing initiatives, it is still essential to estimate performance improvements over time. Having some sense of improvements provides the necessary motivation for companies to follow through with their Lean Manufacturing initiatives in order to reap the full benefits of a more disciplined manufacturing management system.

The Lean Manufacturing planning framework estimates a metric-by-metric performance improvement and then computes an *after lean implementation* overall Lean Performance Rating score for comparison with the *as-is* or current lean score.

Each Lean initiative makes a certain quantifiable contribution to improvement in different Lean metrics and the relative contribution of Lean Initiative *i* on Lean Metric *m* is represented by $\varphi_{i,m}$. The $\varphi_{i,m}$ values can be either 1, 3 or 9 based on the standard QFD approach. A value of “1” indicates a low contribution of initiative *i* for improvement on metric *m*. A value of “3” indicates a modest contribution of initiative *i* for improvement on metric *m*, and a value of “9” indicates a high contribution of initiative *i* for improvement on metric *m*. Table 4 shows the $\varphi_{i,m}$ values obtained from focus groups with Lean Manufacturing practitioners from companies in a variety of manufacturing industries.

Table 4: Lean Initiatives relative impact

$\varphi_{i,m}$ (i ↓, m →)	PT	LE	TML	PTQ	MHTQ	STQ	EPWQ	MWTQ	IWTQ	SR	RR	CPP	IL	IC	LP	CP	SI
Basic Lean	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Error Proofing	3	3	3	1	1	3	1	1	1	9	9	3	3	3	3	3	1
Skills Training Matrix	1	3	1	3	1	3	3	1	3	9	9	3	1	3	9	3	3
Streamlined Flow	9	9	9	9	1	1	1	1	1	1	1	3	1	1	3	3	1
Single-piece flow	9	3	9	9	3	1	1	1	1	1	1	3	3	3	1	1	1
Visual Status Displays	1	3	3	3	1	3	1	3	3	1	1	1	3	3	3	3	3
Preventive Maintenance program	9	9	3	3	1	1	9	1	1	3	3	3	3	3	3	3	1
Line Balancing	9	9	3	3	1	1	1	1	1	1	1	3	1	1	9	9	1
Quick Changeover	3	3	9	9	1	9	3	3	9	1	1	3	3	3	3	3	9
Information Flow Management System	3	3	3	3	1	3	3	9	3	3	3	3	3	3	3	3	3
Performance Management System	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Pull System	1	3	3	3	3	1	1	1	1	1	1	3	9	9	1	1	1
Self Directed Work Teams	3	1	3	3	3	3	3	3	3	9	9	3	3	3	3	3	3
Manufacturing Cells	3	9	3	9	3	3	3	3	3	3	3	3	3	3	3	9	3

The cumulative improvement, Ω_i, from all Lean Initiatives on a particular Lean Metric, *i*, is computed by summing all the marginal contributions from each of the initiatives.

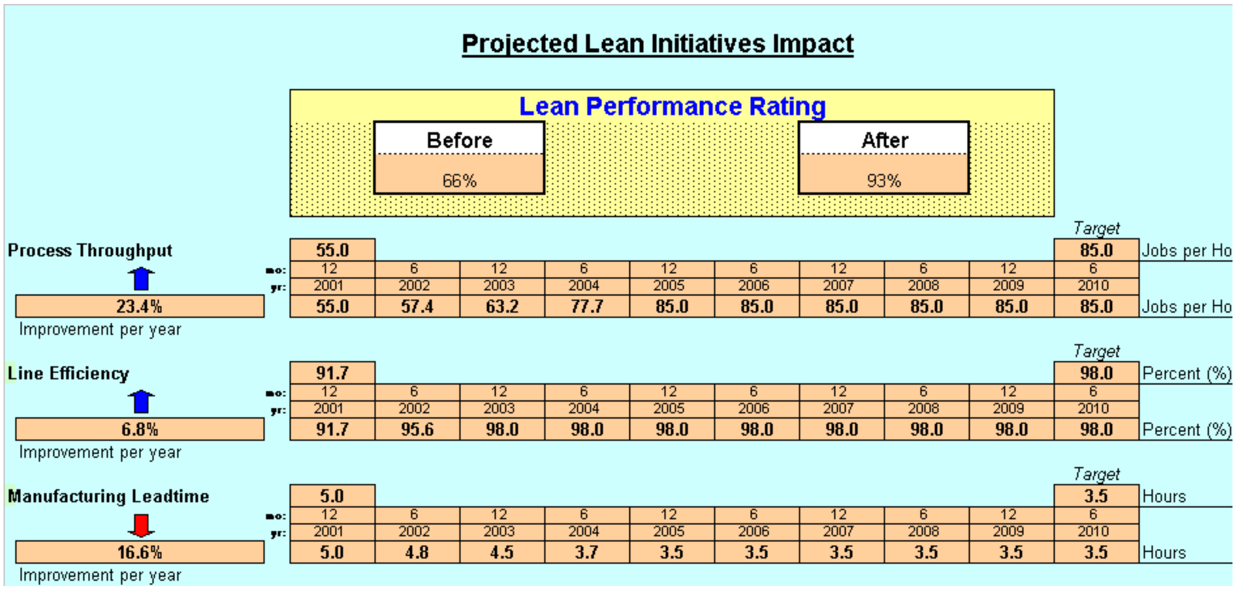
Thus, if:

ε_m is the implementation degree (none, basic, comprehensive) of Lean Initiative m,

Then,

$$\Omega_i = \sum_m \varepsilon_m \varphi_{i,m}$$

Ω_i for each Lean Metric is computed in six-monthly steps based on the implementation schedule for a selected Lean Initiative. Thus, the projected rate of improvement of the metric can be used to estimate the status of each metric over the entire five-year planning horizon. Figure 7 below illustrates the results of projected improvements for the Thypin Co. case study. With estimated performance values from all of the metrics, it is also possible to determine an overall Lean Performance Rating score reflecting the impact of all Lean Initiatives and after the five-year implementation timeline.



Projected Lean Initiatives Impact

Lean Performance Rating

Before	After
66%	93%

Process Throughput — 23.4% Improvement per year

										Target	
	55.0									85.0	Jobs per Ho
mo:	12	6	12	6	12	6	12	6	12	6	
yr:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
	55.0	57.4	63.2	77.7	85.0	85.0	85.0	85.0	85.0	85.0	Jobs per Ho

Line Efficiency — 6.8% Improvement per year

										Target	
	91.7									98.0	Percent (%)
mo:	12	6	12	6	12	6	12	6	12	6	
yr:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
	91.7	95.6	98.0	98.0	98.0	98.0	98.0	98.0	98.0	98.0	Percent (%)

Manufacturing Leadtime — 16.6% Improvement per year

										Target	
	5.0									3.5	Hours
mo:	12	6	12	6	12	6	12	6	12	6	
yr:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
	5.0	4.8	4.5	3.7	3.5	3.5	3.5	3.5	3.5	3.5	Hours

Figure 7: Sample of Improvement Projections for Lean Metrics

BUSINESS CASE FOR LEAN MANUFACTURING

A business case for Lean Manufacturing must be established during the planning process in order to provide a yardstick for evaluating the returns on Lean Manufacturing investments. The business case can therefore be used as a tool for justifying expenditures on Lean Manufacturing and for communicating with both management and line personnel on the efficacy of the Lean Manufacturing effort.

The business case is established through a cash flow analysis of: estimated revenues from sales, estimated Cost of Waste, estimated Cost of Lean, and estimated Lean Savings. Lean Savings are the quantified mitigated reductions in the Cost of Waste due to performance improvements associated with implementation of Lean Initiatives or Lean Manufacturing strategies. Figure 8 below shows the Lean Manufacturing cash flow plan for the Thypin Co. case study.

Thypin Co. Lean Manufacturing Return On Investment (ROI)

Lean Implementation Cash Flow

mo:	12	6	12	6	12	6	12	6	12	6
yr:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Revenues	$ 4,200,000	$ 4,200,000	$ 4,200,000	$ 4,200,000	$ 4,200,000	$ 4,200,000	$ 4,200,000	$ 4,200,000	$ 4,200,000	$ 4,200,000
Cost of Waste	$ (1,653,200)	$ (1,653,200)	$ (1,653,200)	$ (1,653,200)	$ (1,653,200)	$ (1,653,200)	$ (1,653,200)	$ (1,653,200)	$ (1,653,200)	$ (1,653,200)
Scrap	(150,000)	(150,000)	(150,000)	(150,000)	(150,000)	(150,000)	(150,000)	(150,000)	(150,000)	(150,000)
Rework	(180,000)	(180,000)	(180,000)	(180,000)	(180,000)	(180,000)	(180,000)	(180,000)	(180,000)	(180,000)
Inventory Holding	(200,000)	(200,000)	(200,000)	(200,000)	(200,000)	(200,000)	(200,000)	(200,000)	(200,000)	(200,000)
Labor Productivity	(120,000)	(120,000)	(120,000)	(120,000)	(120,000)	(120,000)	(120,000)	(120,000)	(120,000)	(120,000)
Capital Productivity	(600,000)	(600,000)	(600,000)	(600,000)	(600,000)	(600,000)	(600,000)	(600,000)	(600,000)	(600,000)
Process Inefficiency	(403,200)	(403,200)	(403,200)	(403,200)	(403,200)	(403,200)	(403,200)	(403,200)	(403,200)	(403,200)
Cost of Lean	$ (70,000)	$ (85,000)	$ (125,000)	$ (160,000)	$ (170,000)	$ (170,000)	$ (285,000)	$ (285,000)	$ (285,000)	$ (285,000)
Basic Lean	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)
Error Proofing (Poke Y	0	(5,000)	(5,000)	(5,000)	(5,000)	(5,000)	(5,000)	(5,000)	(5,000)	(5,000)
Skills Training Matrix	0	0	0	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)	(15,000)
Streamlined Flow	0	0	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)
Single-piece flow	0	0	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)
Visual Status Displays	0	0	0	0	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)
Preventive Maintenanc	0	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)
Line Balancing	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)
Quick Changeover	0	0	0	0	0	0	0	0	0	0
Information Flow Mana	0	0	0	0	0	0	(30,000)	(30,000)	(30,000)	(30,000)
Performance Manager	(40,000)	(40,000)	(40,000)	(40,000)	(40,000)	(40,000)	(40,000)	(40,000)	(40,000)	(40,000)
Pull System (Kanban)	0	0	0	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)	(20,000)
Self Directed Work Te	0	0	0	0	0	0	(85,000)	(85,000)	(85,000)	(85,000)
Lean Savings	$ -	$ 387,362	$ 734,983	$ 1,002,826	$ 1,266,622	$ 1,332,497	$ 1,369,963	$ 1,411,737	$ 1,443,959	$ 1,464,318
Scrap	0	12,551	32,238	55,195	82,497	102,348	110,872	120,996	128,501	132,000
Rework	0	15,061	38,686	66,234	98,996	122,817	133,046	145,195	154,201	158,400
Inventory Holding	0	8,550	19,750	35,432	58,697	80,900	99,613	119,113	134,826	147,486
Labor Productivity	0	71,820	120,000	120,000	120,000	120,000	120,000	120,000	120,000	120,000
Capital Productivity	0	89,775	217,877	419,532	600,000	600,000	600,000	600,000	600,000	600,000
Process Inefficiency	0	189,605	306,432	306,432	306,432	306,432	306,432	306,432	306,432	306,432
Net Cash Flow	$ 2,476,800	$ 2,849,162	$ 3,156,783	$ 3,389,626	$ 3,643,422	$ 3,709,297	$ 3,631,763	$ 3,673,537	$ 3,705,759	$ 3,726,118

Figure 8: Lean Manufacturing Cash Flow Plan

With Net Present Values of Cost of Lean and Lean Saving estimates, over the five-year planning horizon, it is possible to establish a Lean Manufacturing business case by computing a Return on Investment (ROI) and Payback Period values for the Lean Manufacturing investments. The ROI is determined by expressing the Lean Savings as a percentage of the Cost of Lean (Lean Manufacturing expenditures). The Payback Period computation assumes the Cost of Lean to be a one-time upfront expenditure with the Lean Savings assumed to be five equal annual cash inflows. Figure 9 below shows the Lean Manufacturing Business Case for the Thypin Co. case study.

Lean Implementation Return on Investment

NPV Revenue	$ 32,431,287		
NPV Cost of Waste	$ (12,765,572)		
NPV Cost of Lean	$ (1,397,555)	Analysis Interest Rate	10%
NPV Lean Savings	$ 7,556,922		
TOTAL NPV	$ 25,825,082		
Return on Investment (ROI)	541%		
Payback Period	0.9 years		

Figure 9: Lean Manufacturing Business Case

CONCLUSION

The Lean Manufacturing planning framework has established a unified system for planning Lean Manufacturing implementations. The framework starts with a definition of standard Lean Manufacturing metrics and then develops a quantification of the waste in the system by computing a Cost of Waste value that considers the cost of scrap, rework, inventory holding, labor and capital productivity deficiencies, and production line inefficiencies. The framework also provides a benchmarking and Lean Scorecard module for evaluating performance and setting stretch targets over a five-year period.

For implementation of Lean Manufacturing strategies in order to improve performance, the framework offers 14 Lean Manufacturing initiatives that can be selected and implemented over a five-year timeline. The framework also develops a budgeting system for estimating costs for each Lean Manufacturing Initiative that will be implemented. In addition, the framework develops performance improvement projections associated with the implementation of the Lean Manufacturing strategies. The Cost of Waste, Cost of Lean, and Lean Savings are combined together into a Lean Manufacturing cash flow analysis and business case summary for evaluating costs versus benefits of the planned Lean Manufacturing implementation.

A software implementation of the planning tool has been developed and is available from the authors. This research has been undertaken as an applied research project, and thus, the Lean Manufacturing planning framework and the associated software tool is currently in use to support the Lean Manufacturing programs in several companies.

This research has focused on longer-term planning requirements for Lean Manufacturing. A need clearly exists for tools that support shorter-term and more detailed approaches to Lean Manufacturing, particularly to estimation of more accurate improvements in performance. Future research is addressing this issue and developing simulation tools and axiomatic design methods that permit evaluation, in a process-oriented manner, of Lean Manufacturing strategies such as Pull Systems or Error-proofing.

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