Lean Six Sigma Quality Transformation Toolkit (LSSQTT)*
LSSQTT Tool #23 Courseware Content
“Economic Considerations, Cost Related Documentation
And Quality Relationships”

1. Quality cost and waste: Kaizen, lean
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*Update fall, 2007 by John W. Sinn.

Quality, Cost And Waste: Kaizen, Lean

The idea that costs can be identified and established for control and reduction is pivotal to the fundamental concept of becoming and remaining competitive. But cost identification and/or control is not a simple matter. Definitions vary regarding how we identify a cost, let alone how the information is provided and used. What actually constitutes a cost is also frequently a point of conjecture. As with any data, costs can be manipulated to illustrate a point of view or to appear to be something it is not. Depending on how cost accounting and documentation is done, it may not be a simple matter to truly "nail down" costs of product or process. Assuming costs of final product are fairly well known and agreed upon, how do we determine costs at various points in the process?

The broader context of cost issues is the model for technological change, as introduced in earlier:

The model depicts the way we do our work, make improvement and remain competitive for the future. The basic translation of the model also assumes good fundamental management of resources in production.

One of the keys, at the base of why we include this tool, is understanding and controlling costs. This also qualifies as data and documentation which are pivotal elements in the change model. Knowing where and how to use data and documentation in general is perplexing enough, regardless of type and application. When cost as data and documentation is entered into the equation, it could provide additional elements of complexity. This is true since:

1. Cost cuts across all other circumstances, being universal data for leveling the playing field.
2. While all data can be manipulated and used in ways which may be advantageous at a given moment, cost still translates to profit or loss.
3. Cost reflects all else that we do in production.
4. Cost carries absolute market connections which cannot be denied. If customers do not buy, nothing else matters.
5. Cost is data, documentation simultaneously.
6. Cost truly is the bottom line in the competition. As the saying goes, money talks, others walk.
Data And Documentation Applied.

Complexities are shown within the context of data and documentation nearby. While the complexities of cost related issues are apparent, how to understand and control them are frequently far less obvious. As part of the earlier model, and now reflected in the data and documentation paradigm, along with other elements, cost is at the core, positioned for problem solving and decision making. Consistent with reasons for the team being at the core, it is felt that costs must be centered to the problem solving and decision making process for improvement.

Complexities are first addressed within the tool from the vantage point of economic and cost considerations for doing business. Relationships inherent in cost, waste and Kaizen are presented next in the tool. Broad operating issues associated with profit and loss, and selected cost tools are addressed along with cost analysis for understanding product and production costs. Value analysis focused on understanding and adding value is addressed based on foundational cost concepts, as well as several decision making tools thought to be critical at an introductory level. The tool concludes with inventory issues addressed as fundamental to reducing operating costs.

**Why are we in business—context for cost issues?** Perhaps the first basic question has to do with why we are in business? In the most serious manner, the obvious, simplistic and first response should probably be to be successful. Yet what does it mean to say we wish to be successful within the context of being in business. Aside from the usual reasons of serving the customer, providing jobs, paying taxes to the community, and other "good corporate citizen" type responses, the only real reason for being in business is to make a profit. Making a profit for owners or increasing the shareholder net worth are also translations of the way we say "why we are in business". But the bottom line must be simply to make a profit. This remains consistent with the fundamental precepts of capitalism and our free enterprise, democratic and participatory interpretation of culture as well as community and organization.

How do we educate all persons in the plant to become aware of our need to make a profit, in order to stay in business? More to the point, how do we communicate profitability issues, assisting all to stay in business, grow, and perform well in the marketplace? What are the cost tools we need to use internally to assist us all to document our strategic direction on a day-to-day micro level with people on teams and at various levels and functions? The question of why we are in business relates to all jobs, and how we do them at a personal and team level.

Reasons for being in business could go well beyond what appear to be the more obvious reasons. Strategically, aspects of what we do may be less profitable, but we may be meeting our customers' desire to provide elements of a broader product package. The total package may be rather profitable while elements are less profitable. But if we did not provide the total package, including the less profitable parts, we could potentially lose all of the business. It may be that this provides a good starting point for us to look for improvements—enhancing the profitability in those parts of the program which are less profitable. The way we engage the customer (fundamental to keeping their business) will also relate to our broader supplier and customer relationship. This is why Kaizen teams frequently involve external customers as part of the group.

Another strategic reason for being in business, and not being as profitable as we may wish, could include positioning ourselves. It may take years of effort through many growth cycles to gain sufficient market share to be as profitable as we wish to be in a given sector or product line. Or through a combination of acquisitions and new product introductions, we may be able to become increasingly profitable over time. But it may have only been possible by long range visioning and careful strategic maneuvering. This would generally include internal re-organization to better meet customer demands and increase profitability. Yet this will also require careful use of data and documentation based decision making for improvement over time.

This tool provides several specific approaches to assist teams and others throughout the organization in understanding and communicating regarding cost issues, all aimed at enhancing profitability. The context of "why are we in business?" and "how do we stay in business?" is woven throughout, and further developed. Specific topics included within the toolkit context are Kaizen, cost and wastes; P & L, operating statement; types of costs; break even analysis; product cost analysis; value analysis; and, capital investment analysis. Each of these could be pursued at length and in depth as individual tools and techniques. These are presented here only as a start point for teams and others to use as we pursue improvements in operations.

**Other broad cost relationships.** In terms of relationships, the greater the costs in the organization, the higher the price of the product, and the less competitive the organization. This assumes
the market will permit the higher costs to be passed on to the customer. The more carefully costs are analyzed and controlled the more likely are the chances of having a productive, profitable, competitive production system and overall organization. This relates to quality, based on how well we understand what we are supposed to be doing to meet customer demands, how well we have put our systems together to produce products, and how we go about detecting, correcting, and improving over the long and short term. This requires some brief discussion on the context of quality, and how we use cost information alongside other documentation and data to assist teams in making improvements.

Theoretically, certain kinds of costs, associated with the improvement and control of product quality, can provide a means of measuring and optimizing total quality activities. From the macro point of view, costs for attaining and maintaining acceptable levels of product quality are brought together and compared against costs resulting from failure to obtain the particular level of quality. Such consolidated costs are frequently identified as general quality costs. These general costs are often further defined as defect prevention costs, evaluation and appraisal costs, and failure costs. Each of these will be briefly discussed within the broader view of quality and "staying in business", from the previous topic. This is also presented within the broader context of the toolkit and Kaizen systems based on data, documentation and synchronized leadership for the future.

**Prevention costs.** Prevention costs are generally thought of as "front end" relative to actual production and include quality planning and costs associated with preventing defects in production as well as failures in the field. This generally involves such cost areas as quality engineering in the design stages, and early stages of product launch. Other elements involved in the front end would be part approval systems, short and pilot runs, training, audits, supplier development, and general implementation of systems to meet customer demands. Much of this is presented as macro issues in the toolkit synchronous leadership functions, focused on product launch, provided as tools 49-60. But this may also be viewed as micro functions at the team level since, throughout the life of the product, we will want to continually improve the product performance. Much of the current 37-48 Kaizen tools are focused on short term improvements incrementally gained and adding to the overall aggregate profitability of the organization.

**Evaluation or appraisal costs.** Evaluation or appraisal costs are those costs incurred in evaluating product quality to maintain established quality levels including such areas as measurement systems (calibration, inspection and testing costs); charting at the line; supplier surveillance; and other broad assurances in production. Once again much of this must be accounted for at the macro level in broad terms over time to determine impact on the bottom line. But at the micro team level we must track data through charting and in other ways to demonstrate frequency of inspection, value of information being obtained, and other important day-to-day data. And after all, if the data being tracked at the operator level is not reliable, the broader macro accounting data will be less useful as well. The assumption in the toolkit is that data and documentation in the forms of SPC, gage R & R, attribute and variable charting, and ultimately more robust tools such as design of experiments, will provide the basis for evaluation and appraisal of the broader system, all aimed at improvements. Other tools in the current set are also aimed at helping evaluate ourselves in various ways, including bench marking and auditing, understanding our processes, and the OPCP and SOP tools.

**Failure.** The final broad quality cost area is failure. Unfortunately, occasionally we will have product failures in the field or, hopefully, prior to them getting out the door. And again while some of this cost must be shared with detection and prevention as well as with appraisal, at the point of failure it does not matter a great deal where we log the cost on the ledger sheet. This is clearly a loss in every sense of the word, and the best that can be said about failures may be that they do represent opportunities for learning and improvement. These costs are further identified, for quality purposes, as service and warranty, rework and scrap, corrective action costs, product liability issues, engineering changes, redesign and so on, all aimed at straightening out the problem noted as failure. From the Kaizen systems perspective in the toolkit, this includes the FMEA and QFD tools, OPCP and SOP development, and others in the current set of tools. Also, much of the broader synchronous leader function in tools 49-60 focuses how we juggle use of engineering analysis information such as finite element analysis (FEA) back into broad product improvement in a natural and automatic way through cross functional teams at various levels.

**Waste and Kaizen systems.** The basic concept being discussed, while broader within the context of quality costs and staying in business, at the macro level, is also pertinent to waste identification within
Kaizen as a team micro function. The basis for long term improvement and profitability is clearly associated with our cultural ability to do team based improvements aimed at identifying and reducing wastes as measured ultimately in costs.

The Kaizen system is presented as a team based function requiring cost data along with other key documentation for decision making on improvements to enhance quality. It should be noted and underscored, much of the basis for solid decision making and evaluation is the quality data being gathered and analyzed at the cross functional team level, including operators and supervisors, as well as technical support persons. This also provides both a micro team view and a macro organizational view, and provides waste identification and follow through for broad and immediate improvement focused on profitability. The issue of costs associated with all improvement are both pivotal and a natural part of the profitability question for staying in business.

P and L, Operating Statement

The P and L, or operating statement, sometimes called income statement, provides one of the best overall indicators of our financial performance. The P and L provides a summary of our performance based on income versus outgo, in layman's terms, or more accurately, profit versus loss. This is further explained within the current section, all focused on broader issues associated with competitiveness. It should be remembered that the categories and ways of showing cost information will vary from organization to organization.

Profit. Sales usually begins the statement at the top of the sheet, as measured in what is termed cost of sales. Cost of sales are those costs which are typically associated with raw materials, direct labor, and factory overhead. Factory overhead is further defined as indirect labor, scrap and rework, depreciation on equipment, and various support groups or departments such as purchasing, engineering, quality control, among others (commonly also referred to as standard cost of sales). Cost of sales are subtracted from actual sales income, deriving what is termed gross profit. As is shown in the example nearby, there are also variances which may affect gross profit, up or down (+/-). These would include material obsolescence, warranty work, production efficiencies, and so on.

Net operating profit is then ultimately derived by subtracting general selling and administrative costs from the actual gross profit, providing a net operating profit. The general selling and administrative costs are identified further as administration, marketing, distribution, research and development, accounting, among others. Based on the net operating profit, interest and/or other miscellaneous cost inputs may be included for a final pre-tax profit. Taxes are a negative value against pre-tax profit, generally at approximately the 50% level. After tax expense is removed, the remainder is net profit after tax. It should be noted in our example that we have gone from one million dollars to a net profit after tax of $50,000.00. While this is somewhat dramatic, and over simplified, it still speaks to the point that profitability is not a simple matter to be taken lightly. This also may speak to the reality of why many organizations have chosen to invest moneys in other more profitable activities, and perhaps even gotten out of manufacturing all together.

Loss. It should be pointed out that the reason the P and L is called the profit and loss sheet is because there could be the circumstance where a loss is incurred rather than a profit. This, of course, is to be avoided wherever possible. The goal is to show a profit, the more the merrier. Losses generally occur where waste is running rampant due to poor management or for other reasons. Poor performance in the marketplace will obviously affect P and L, as will over investment in new equipment or new product development, among others. Cash flow, in the above circumstances, becomes pivotal for keeping a healthy P and L, yet this may be easier said than done. An example P and L follows to illustrate what is being discussed.

<table>
<thead>
<tr>
<th>Sales</th>
<th>$1,000,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cost of Sales</td>
<td>700,000</td>
</tr>
<tr>
<td>Gross Profit</td>
<td>$300,000</td>
</tr>
<tr>
<td>+/- Variances</td>
<td>-0-</td>
</tr>
<tr>
<td>= Actual Gross Profit</td>
<td>$300,000</td>
</tr>
<tr>
<td>- GS &amp; A</td>
<td>-200,000</td>
</tr>
<tr>
<td>= Net Operating Profit</td>
<td>$100,000</td>
</tr>
<tr>
<td>+/- Interest and Other</td>
<td>-0-</td>
</tr>
<tr>
<td>= Pre Tax Profit</td>
<td>$100,000</td>
</tr>
<tr>
<td>- Taxes</td>
<td>$50,000</td>
</tr>
<tr>
<td>= Net Profit After Tax</td>
<td>$50,000</td>
</tr>
</tbody>
</table>
Broader issues. Some of the broader issues have been referred to earlier. These can include growth versus stagnation, product development for remaining competitive, changes in the organization for realignment in the marketplace, and so on, all generally healthy signs. But obviously, if we do not handle these situations carefully we can create a negative cash flow in the P and L, leading to poor performance over the short or long haul. Generally, the P and L will be issued monthly and used in comparison to budget and previous year's performance. As we set our strategic vision in motion, we must have a firm grip on the financial situation. The indicators we get over time from the P and L, are among the best gages of performance.

Selected Costs, Economic Tools, Terms

Several key terms can assist us in better understanding the overall production picture, and facilitate our desire to improve the same. Some of this has already occurred as we have become introduced to the P and L, waste and general quality costs. The context of all of this was "why are we in business?", and of course, there are other important elements and parts of the equation. The purpose of the current section is to assist us in seeing yet further economic details of the complex behaviors which are at work in the organization. We will briefly explore cost, investment, direct and indirect costs, standard costs, and other related cost issues. The stage will also be set for other actual economic analysis tools which should prove useful for making effective decisions and managing at various levels. All of the information is presented within the context of being used by teams and others to improve our competitiveness. No explanations offered are viewed as anything more than the bare introduction. All will require further discussion, study and research.

Capital. Capital represents the resources we have to work with. It can be represented in assets such as buildings and equipment, cash on hand, human resources, or inventories of product, materials and components. Capital provides the mechanism wherein we convert our resources into good or services to meet customer demand. This has obvious relationship to adding value.

Cost, profit, selling price. Cost can be defined as what we pay to produce our products and services. Thus it should be clear that one way to increase profits is to reduce costs. There are at least two ways we look at the inherent relationship in cost and profit:

\[
\text{Cost} + \text{Profit} = \text{Selling Price}, \quad \text{or}
\]

\[
\text{Price} - \text{Cost} = \text{Profit}
\]

Though these are algebraically identical, they deserve further analysis. This is true for many reasons but fundamentally since the producer does not set the selling price. Rather the customer (market) will determine selling price, as in "what the market will bear". Unless we have a product which is without competition, we can not simply allow our costs to run rampant, and tack on what we think to be a reasonable profit margin. While this may be possible in an economy which is booming and which has high demand, the reality of the market place is typically much different. Profit is a function of relating product costs to selling price at a minimum level, providing a positive level of profit competitively.

Fixed costs. Fixed costs are those costs which tend to be required simply to do business. While we may have some control within the latitude of volume and type of production, fixed costs will be there and must be addressed as a cost of doing business. Fixed costs are typically further broken down into rent; insurance; taxes; depreciation; salaries; and, power. Fixed costs tend to be of a macro orientation, not associated with any one product or element of production.

Variable costs. Variable costs, while still macro in orientation, are those costs which we tend to have some degree of control over, and usually directly associated with the act of production. These would typically include such items as direct and indirect labor costs; travel expenses; and materials and supplies. Variable costs are not necessarily associated with any one product, but do vary with level of production.

Direct and indirect costs. One way to look at costs for further analysis is direct and indirect costs. Direct costs are associated with actual production of a given product. These are commonly material and labor, where the value is directly added. Indirect costs, therefore, could be generally identified as any cost not directly associated with direct production where value is clearly added. Indirect support costs are usually identified as inventory, engineering, marketing and sales, maintenance, quality and so on.

Standard costs. Standard costs in production are those which we can predict from time and/or other standards. Derived from continuous production of discreet components or product, we can predict,
from experience, what will be involved in producing the product. The information will be reflected in a bill of material, routing form or anticipated indirect costs, and will likely show all material and labor, and other costs, required to bring the product to fruition. Standard costs provide a mechanism for efficiently and effectively quoting on contracts and responding quickly to customers. They also provide an effective tool for helping track our costs in production.

**Cost centers.** Cost centers are associated with accounting procedures and relate to our desire to track costs as a function of where value is actually added, or costs are directly consumed. Cost centers tend to be determined and structured based on product, process or administrative function and are not necessarily oriented only toward the immediate act of production. Discreet focus of the center for tracking costs is required if actual accountability is to be a useful outcome. This is consistent with teams and accountability in empowered circumstances since true empowerment requires cost control.

**Cost accounting.** Cost accounting is a basic administrative activity which is concerned with determining and monitoring cash flow. Cost accounting studies monetary activities related to processes, materials, products, departments and other general cost factors. Information supplied to cost accounting will aid in determining organization budgets, profits, production levels, and which products are profitable and should be continued. Also general efficiency levels throughout the organization, issues related to expansion and other matters depending on the nature of the organization and its products, can be considered.

Cost accounting data is accumulated in essentially three ways. The three methods for cost accounting are job, process and standard. Each of the three will be briefly explored.

Job cost accounting relates to producing individual, unique, products and it is desirable to know each product cost. Job shops are examples of typical users of job order cost accounting systems.

By contrast, process cost accounting accumulates costs for running each department or operation within the organization. The accumulated cost is divided by the number of units completed in a department or operation to estimate the average cost per unit. Process cost accounting is generally used in continuous flow production organizations.

Standard cost accounting relates to standard costs presented a few paragraphs earlier. Based on standard data and cost information built through experience over time, accounting information can be built for jobs or processes. As with most else, the reality is that a combination of the above are used.

**Investment.** Investment is a term which is bound to come up in the discussion related to costs. This is true because it costs to have investments as part of the overall economy of the organization. The investment cost is a negative drain on profit, moneys which could have shown up as a positive on the balance statement. But, what are the investments and why would we do them? Examples could be:

1. New or replacement equipment.
2. New or replacement tooling.
3. Reorganization.
4. Marketing realignment and expansion.
5. New product development.

It is important to note that all of these, in one way or another, relate to growth. Each are strategic planning and positioning type issues or circumstances for our future. If we wish to remain competitive it is imperative that we carefully and judiciously place a portion of our assets into these kinds of programs for the future. How much and of what kind will depend on the nature of the organization, the competition, our customer base, and so on.

**Cash flow.** Cash flow is part of the way we talk about how our dollars are tied up in various investments, direct production functions, and in other ways particularly associated with indirect costs such as inventory. As was indicated earlier, the dollars being dedicated to production are offset by income due to sales. The overall financial behavior may be referred to as cash flow as one indicator of our performance. Simply, if we have poor collections on sales, too much debt to be serviced as a function of investment, or outgo which outweighs income in any other manner, resulting in sluggish income versus active outgo, we would say we have a negative cash flow. Equally as simplistically, if, on the other hand, we have income outweighing the outgo, we would say we have a positive cash flow. How good or bad in either direction is a rather complex matter, and would be measured based on information and techniques beyond the scope of the current tool.

**Interest.** Interest on money is important since it represents the amount money can either command in the market place, or the amount money will cost if we must borrow to it. Simple interest is that interest which is calculated directly on the amount used for only the actual period specified. Compound interest is calculated on the amount accrued in multiple periods, plus interest for the periods.
**Productivity.** Productivity serves as one of the fundamental measures of economic and cost related measurements for success. The productivity measurement is similar to a efficiency rating in that we divide our output by the inputs to determine a ration. Productivity is a indicator of performance for an individual operation in a micro sense or an entire organization in a macro view. Examples of the types of measures which could be used to analyze productivity could be:

\[
\text{total sales} \quad \text{materials handled} \quad \text{sales expenses} \quad \text{worker hours worked}
\]

By using actual values representing the denominator and numerator, we can derive a percentage as an indicator of performance. This performance indicator of productivity can be used as a baseline for future comparisons, and in other ways.

**Payback.** Payback asks the questions, “what impact will an investment or acquisition have on our financial performance?” The payback process generally tries to document project life, savings over some period of time, and costs to do the project. This is all put together in some return on investment (ROI) type format for presentation and analysis by and with management. More complex approaches take into account the value of money at the time it is being used, present and future value, economic depreciation of equipment, and perhaps other variables.

**Break even analysis.** Break even analysis (BEA) is an economic and cost equation which relates costs, sales volumes and income to determine that theoretical point in the future where we can expect to break even, and begin to show profitability in production. This will be addressed in some detail in a later section and is also demonstrated as a graphical model.

**Materials requirements planning.** Materials requirements planning (MRP) is viewed as an economic and cost issue, and presented in a later section of the tool since it connects fairly matter of factly in production. Costs directly associated with MRP are inventory related such as carrying costs, reorder costs, cost of inventory, and so on. Indirectly, costs of work in process, or WIP, as it is called, while not a simple matter to determine is a substantial element in the costs paradigm to be addressed and wrestled with. In fact at the heart of much about Kaizen is the issue of reducing inventory on the shop floor as well as in warehouses, thus reducing costs in production.

**Push and pull production.** While we understand production is a function of inputs being converted into useful outputs, we may not understand that two important different approaches within the production equation are possible. By way of introduction, and to be followed with more discussion in a later tool, the two are push and pull production. Push production is the traditional approach to production where we anticipate demand by way of forecasts and past history of product requests, stockpiling product in production. Pull says let the job order drives production. We do not initiate production until the order has been provided by the customer, and we are done with production when we have filled the order. Push is “fatter” while pull tends to be “leaner”, with push having more costs tied up in inventory and pull being more cost effective.

**Product Costs, Kaizen, General Cost Analysis Factors**

Product cost analysis provides the opportunity to identify and track costs in the product being produced. As should be fairly clear, based on the preceding discussion, identification of costs is pivotal to getting a handle on production. Having accurate information on costs would be analogous to tracking quality attributes or variables for improvement. If our basic assumptions about what to track and how to record, as well as frequency and tolerances, and so on, are not appropriate, we simply will not have the end product required for effective decision making. This is also consistent with several tools which follow this one, where we discuss in great length the need to understand process. The premise is that we cannot understand production process or product without a thorough understanding of costs. Three approaches are taken for cost analysis, including product cost analysis, Kaizen cost analysis, and a micro and macro cost analysis, each briefly presented and explored.

**Product cost analysis.** A form is provided in the applications section showing one basic approach which includes cost categories for information pertinent to the task. These include part name, materials, operation or function, specifications and direct and indirect costs. This can provide details on specific costs and is easily organized and readily understood (particularly for more complicated technological functions or activities), and provides the ability to condense information into a manageable form, including sub-cost totals for each itemized
category of inputs. The use of this form is intended merely as a start point for attacking actual product costs. It is not intended as an end all device or system, but rather as an analytical aid for individuals and teams trying to determine actual cost of product or production.

A feature worth noting relative to the columns and categorization of cost information is the ability to computerize this approach. With the advent of spreadsheet software, cost information which starts out huge can be advantageously placed in this format. Other advantages should be considered:

1. After the information is computerized it can be shared with other individuals who have similar computers and software capability, presumably networked in some fashion. A logical assumption is that organizations would provide all users of this information with the capability.
2. This information can be originated in accounting or interfaced with accounting. Although it is quite likely that it is best to control this information at its point of origin, as in cost centers, there can be little doubt that the more efficiently and accurately we can maintain this information, the better we will provide a clear competitive edge.
3. Regardless of where cost information is gathered and/or housed, it must be shared with/accessible by all in the organization. This could include inventory, engineering, quality and other production personnel. Yet, as with any information which is used by multiple teams and/or individuals, integrity and security of information must be carefully addressed.

Computerization of this information can assist in the overall need, and provides a clear advantage. As with any other cost analysis tool, in any technological environment, following a detailed identification of all costs at the micro or macro level, an in-depth analysis of each cost factor can provide additional cost information. It is only through identification and analysis that costs can be driven down, since what is not identified and/or analyzed can not be reduced.

**Kaizen cost analysis.** Kaizen cost analysis uses data supplied from other sources, but consistent with the Kaizen systems presented throughout the toolkit, places these in a documentation form for analysis. Much of this is touched on, and introduced, in other sections relating to methods analysis, and then more thoroughly explored in several tools dealing with process analysis. The analysis and use of cost, time, methods and other process oriented data in a systematic manner is what provides the opportunity for improvement. The form used in the Kaizen cost analysis approach is provided in scaled down version nearby. The Kaizen cost analysis form requires gathering and analyzing a fairly significant amount of information in areas not commonly thought of as cost drivers. Most of the areas relate more to methods analysis and common Kaizen functions. When these are identified and estimates for costs determined and listed, robustness of cost analysis becomes clearer.

**Micro and macro cost analysis.** At the micro level, material and processing cost analysis is concerned with determining and selecting the most cost effective material and process for a specific product application. This provides a general focus for continuous improvement in virtually all aspects of production, and should be of optimum interest to all, ongoing. As we consider strategic issues of a longer term concern, we should address these broad cost categories at micro and perhaps macro levels. The following cost factors should be considered:

1. **Weight.** The least weight and amount of material for satisfactory strength is necessary in products. Can we find a less dense, or lighter, material which will perform the necessary tasks of the customer?
2. **Service requirements.** How well will a material or process perform where the product is used? Such service demands as dimensional stability, corrosion resistance, strength, hardness, and thermal and electrical requirements must be provided by the material for the product at minimal cost. Can production equipment hold performance specifications over time?
3. **Maintenance costs.** How frequently, and in what ways, must the material (product) be maintained? How frequently must the product and its components be lubricated or serviced? What maintenance issues are related to process? This also includes considering power consumption, set up costs, fixturing, and so.
4. **Transport and handling costs.** How much will it cost to transport materials for production? Will new handling equipment be required for materials under consideration? Can materials handling costs be reduced if a different material is used? What about transportation issues after assembly for final ship?
5. **Processing capabilities.** Which material can be most readily processed with existing processes? Will new processes be required? Have process capabilities been considered (types of operations which can be performed as well as statistical process control capability)? Do we have operators to operate equipment?

6. **Storage and contract costs.** Can the material be stored with the existing inventory system? Are there shelf-life or environmental control concerns for materials which may lead to increased costs? Will processing capabilities need to be sub-contracted? Will we need to acquire additional space and/or equipment?

7. **Preparation costs.** Are special preparations required at some stage in production which may lead to increased costs? For example, hot rolled steel may require surface finishing when compared to cold rolled steel, depending on product finish requirements. Also, can a material be used which can be purchased in pre-manufactured shape or condition such as tube, perforated, angle or others?

8. **Availability.** Is a material or process being used which will continue to be available? If not readily available, can a cost effective substitute be located? Can existing processes be used for substitute materials? Is the supplier capable of sustaining a long term relationship?

9. **Aesthetics/market appeal.** Is a material being used which is sufficiently addressing the market in terms of both aesthetics and functional service requirements? Can a different, more effective, material provide sufficient appearance to meet the products' market demands? Will processing afford adequate quality in the marketplace?

These provide a basis for analysis and comparison of various materials, processes and costs, and both for new or existing products, can lead to substantial cost reductions. When organized in a form as shown in the applications section, many of the cost factors can be more fully addressed by teams who may need to plan for new products or improve existing production.

We should have records on hand to aid in analysis of many of the above listed considerations. If a product or sub component is being analyzed for cost reduction, we can conduct studies to determine the most cost effective and productive process. Process advantages and disadvantages can be listed for comparison and ultimately, optimal processing capability. Additional typical production process areas to study for cost reductions and increases in productivity might include the question, can some operations be eliminated? This could include deburring, redrilling, polishing, reaming, etc., in general production. Can some operations be combined? This could include retrofitting, multiple operation machinery, drilling/reaming, and multiple part tools, among others. Can the efficiency of the operations be upgraded? This might include substituting machine operations for hand operations, power screw driving for other types, automatic feed, automatic screw separators, and substituting tools of longer life. Likewise, can some processing components be recycled or reclaimed? This might also include re-using chemicals in a photographic application, saving residual aggregates in construction for recycling, among others.

### Value Analysis, Value Added, Quality

When considering costs in product and production, it is inevitable that the issue of value must be addressed. Value blends actual costs with aesthetics, market appeal, quality and other cultural issues which may be less tangible and definitive. If we consider the extent to which consumerism has impacted our concept of value, and changes in the way quality is defined, perhaps value can become somewhat confused in the cultural sense, as well as in the strict production sense. Personal values clearly are a consideration in determining value in product. If I do not value a given product or component, I will likely place a smaller value on this product or component relative to others. Similarly, if customers do not value a given product or component, they will likely reflect this to the supplier in ways which may result in less contracted work at various levels.

But what does value added mean? Some years ago when discussing "value added" in production or product, the concept seemed fairly straight forward. Simply stated, added value has traditionally been regarded as changes in materials, particularly from the manufacturing or construction sense. As we transform an ore into a material which becomes increasingly useful, and ultimately is converted into a product which is demanded and valued by customers, we would traditionally say value has been successfully added. Years ago this was traditionally based on value added as a function of manual labor with relatively crude technology and equipment, as well as rather "undefined" customer demands. This
has also become value added with automated systems, devices and equipment—but clearly with less emphasis on manual labor as a point of adding value.

As shifts have occurred culturally, resulting in sharper customer demands, less manual labor and increased mechanical and automated inputs, we can see that value added may be a foggy issue at best. Moreover, no longer is all work a discreet change in product through materials transformation. It is just as likely that a programmer, clerk or operator must add value in non-traditional ways which are much more difficult to measure relative to traditional discreet ways such as changes in materials. The programmer may work for hundreds of hours to correct a seemingly minor "glitch" in software which otherwise simply prevents us from accomplishing the necessary task. Clerks may perform essential documentation functions, and the operator is less and less likely to be adding value in absolutely discreet and discernible ways, increasingly true as shifts to broad job descriptions and cross functional work occurs.

As the concept of value added has become increasingly clouded, the task of determining costs in production have been similarly called into question. What was traditionally a rather straight forward time and motion study to determine standard costs for bids and contracts may no longer be sufficient. As the production environment has shifted to an increasingly automated and service oriented situation, have we factored this into the cost scenario, and how? As methods have shifted to empowered work teams, with responsibilities at lower levels, have we considered new models for costing and valuing work? Are the traditional categories of direct and indirect costs, and materials and labor, still sufficient for the newer cyberspace type products, methods and systems which are increasingly becoming prevalent? Can we even compare some of the newer circumstances to the traditional models, and are older models applicable?

And what are the implications for quality? Culturally, as shifts have occurred in other sectors and circumstances, value added in traditional ways has not always resulted in an enhancement to quality. A good example of this could be the 1970's when Americans were caught in the middle of a fairly confusing period with reference to automobile transportation issues. We were squeezed by the "oil crisis" which was causing a dramatic rise in the cost of crude oil and gasoline at the pump. We were also downsizing our automobiles from the muscle cars of the 60's, and trying to figure out how to do economy cars. Concurrently the Japanese came to town and began to redefine the quality of the automobile in fairly definitive terms, virtually revolutionizing the entire industry, and others along the way. In the period of a rather short few years we have gone from a fairly bulky and inefficient gas guzzling automobile to lighter, less powerful, longer lasting vehicles. Value was redefined in the context of definitive quality measures and changes in cultural paradigms.

Value analysis. Value analysis, or engineering as it is sometimes called, can be used in design cost analysis to help determine the value of various components in a product. Based on the previous discussion related to value, cost and quality, it should be clear that value can not be assumed to be apparent or appropriate in a given component, product or service. We must continuously strive for improvements and cost reductions.

The system discussed requires a thorough understanding of the product and its functions, and the ability to assign value to functions. After value has been determined various cost reduction attempts should be made through the critique process known as value analysis. The significance of this point can be noted by observing the difficulties in trying to make improvements in workers and systems "after the fact" rather than in the planning stages. This is not to say that value analysis can not or should not be used in ongoing mature production, nor that it should be limited only to new product development.

The broader concept inherent in "value" requires further discussion, particularly as related to value analysis. We all know there are multiple ways to accomplish various tasks and applications. The question generally becomes which way is the best way? What if we have been doing it the same way forever, or more to the point, "if it ain't broke, why fix it"? Value analysis causes persons to consider that there may be better ways to do what we are doing.

Several key "value added" points identifying proper design strategies for cost effectiveness are identified in the following listings:

1. Use standard sizes and parts.
2. Use large tolerances whenever possible.
3. Plan for largest lot size possible.
4. Design for simplicity--no frills.

In each of the design points listed costs can be reduced. Obvious savings should result when standards are used. Larger tolerances typically result in higher production levels and less human input, reducing costs again. Larger lot sizes can result in less set-up time, less retraining, possible increased
use of automation and perhaps other cost reducing possibilities. Design simplicity, generally resulting in value added, can result in less weight, less components and fewer processes. Additional design questions which should be considered by technologists in an attempt to study product cost reductions and value added, could include the possibility that materials, parts and components can be eliminated. This could include screws rivets, washers, brackets, and so on. Can the function of several parts in the product be combined into a simpler component design? Can the shape of parts be changed to reduce size, thickness, scrap materials, or operations to produce the product? Can material or processing requirements be substituted to make the design more cost effective? This could include exchanging aluminum for brass or plastic for metal, casting for machining a component, spraying for plating a finish. This could also be questions relating to the product being redesigned to incorporate upgraded efficiency in processing, or using a different machine or process which can be purchased.

Value analysis is discussed here as a design function, but it can also be quite useful for general cost reduction of existing products' redesign, as opposed to a first-time design. Fundamentally, the aim of value analysis is to identify and remove areas of excessive or unnecessary expense from products or projects. Virtually any part, component, procedure or service related to the product or its system can and should be subject to the process of value analysis. Value analysis is a process which asks questions about the product in an attempt to reduce costs related to the product.

Based on the form provided in the applications section, the steps, corresponding to the major categories of information follows, both categorically and in graphical form. It should be noted that these steps may take several iterations or sessions to complete, and are certainly intended to be on-going in nature. The process is also designed to be conducted in the team atmosphere:

1. **Part/component.** The item being analyzed, within the bigger assembly or component, is listed or identified. This may include other information being attached or referred to.

2. **Function/purpose.** The function of the part under analysis is described and analyzed. Action oriented verb terms describe function:
   - position
   - hold
   - transmit

3. **Value rating (1-10).** A qualitative rating is assigned based on the individual or team view of the component or part under study. If the part is perceived to be of little or no functional value to the product, a low value is assigned, and a necessary component ranks high. Similar values can be assigned to different parts.

4. **Cost.** The cost of the part under study is identified, the manufactured or supplied cost.

5. **% cost total.** What percentage of the total product cost does this part represent? Part cost compared to total product cost is of concern.

6. **Value added weight.** A simple calculation of the value rating times part cost times percentage from above is derived. This provides a numeric value of our collective view on value of components.

7. **Compare part values.** After each part is analyzed and values are derived for each, they should be contrasted and compared for likely areas of improvement and optimization.

8. **Alternatives identified.** Various possible alternative materials and processes should be identified and explained for follow-up. This can be brainstormed and fishbone cause and effect tools used for recording information.

9. **Value analysis statement.** A general summary or conclusion of the overall activity is explained or offered. This would typically assist others in understanding why selected values were shown as they were.

The basic question "what is the functional purpose of the component" is raised?

These steps are generic in nature, intended to be applied in various ways to various circumstances.

Value analysis should be perceived as a positive and contributory element within an organization. It may prove to be a threat to many individuals since it often involves finding faults in design, materials selection, processing, distribution and so on. Diplomacy must be used in the value analysis process, through meetings, open discussions, individual face-to-face meetings, etc., if people are to feel non-threatened throughout the process.

Summarizing basic precepts in value analysis:
1. **Ongoing improvements.** Knowing there is always a better way to accomplish something in a product or system.

2. **Establishing costs.** Determining, precisely, the function and cost of an operation, part or service in the product.

3. **Cost vs. function.** Establishing a cost and function relationship among operations, parts or service in the product.

4. **Design change impacts.** Determining what effect a change in cost or function might have on the overall product.

5. **Cost vs. performance.** Achieving functions at the lowest cost without compromising performance or quality in the product.

6. **Counter productive elements.** Internal competition and petty infighting is counter productive, and we must all give and take with our ideas, methods and general concerns.

7. **Value added.** If we improve the overall value of our product, we enhance profits, providing the necessary competitive edge and overall likely success of our organization.

Although the process of value analysis can occur in many different ways, many which have been identified, the basis of the process relies on determining current part costs related to function, materials costs and so on. After a clear determination has been made, including documentation as appropriate, including drawings and specifications, and perhaps in other ways, it is then possible to complete a formal analysis with the possibility for proposals for cost reductions. However, and this should be underscored, it is essential that documentation be recorded at each step of the value analysis. Value analysis should be regarded as a healthy, positive activity to be encouraged.

**Methods, time and cost analysis, process improvement.** Methods will be more thoroughly treated in the next tool as part of process knowledge and understanding as the basis for improvement. It is, however, appropriate to introduce elements of the relationships at this point, as part of the cost area. Obvious reasons for this relate to important connections between cost of labor and potential improvements leading to cost reductions in the same.

As related to cost, methods are briefly addressed for purposes of establishing the connection between methods used and time consumed to process product. This relates to manual processing as well as automated, and provides the basis for much which was presented earlier related to direct and indirect labor. Although time and methods as used here are primarily associated with direct contributions for costing purposes, obviously all labor costs should be studied for cost reductions wherever possible.

Also to be studied further in the next section, process improvement will be the major focus of several tools in various ways. Cost relates to the way we have laid out the work area, the flow of product through the processes, routing and scheduling, the way we inventory product and components, and much more. Kaizen systems are also briefly reinforced here since we are discussing how to achieve the lowest costs for maximum quality in production. The way teams work to achieve maximum productivity with resources available is the primary focus. This will become increasingly important throughout remaining parts of the toolkit, and cost is a key part of this.

Several rather simple forms are provided which are intended to assist teams and others work to improve processing areas. The first form is the standard time and method analysis form. This form is more thoroughly discussed in the next tool, but is designed to determine time and processing method in a flow chart context for analysis and improvement. One column is also provided for cost estimates, as noted on the far right side of the form.

Based on time and method, assuming more knowledge in the Kaizen realm may be desired for line balancing and enhanced scheduling, an SOP with takt analysis capability may be warranted. The takt analysis provides a basis from which to better balance work loads for efficiency in production. While the fundamental issues involved are related to costs, time and process improvement, emphasis must also be considered relative to comparison of potential process improvements. If after various analysis have been conducted, specific options can be collected for comparison, a form is provided for listing and analysis. This form also provides a category for cost estimates. In all cases, as cost and other methods oriented data becomes known and documented, process improvements should be identified which can reduce variation in balance and load at processes, and improve quality performance of operators. The intention, connected to several previous sections in the tool, is to help assure that value is being added in ways consistent with remaining competitive.

It is suggested that teams and individuals can use the form to identify opportunities for improvement, and in conjunction with other forms and Kaizen systems, can proceed to conduct systematic improvements at the processing level.
Break Even Analysis

An important cost control tool presented for enhancing competitiveness is break even analysis. Briefly introduced earlier, this tool shows relationships between various cost factors, production levels, profit and loss, sales income, and other organization cost factors. Break even analysis is particularly helpful in attempting to get a handle on the big picture in production and other technological issues. However, it can also help in looking at very specific production circumstances such as a given work area, operation, or machinery/process comparison. Regardless, break even analysis is typically shown either as a schematic/graphical representation or as a mathematical model. Mathematically the break even analysis is shown as:

\[
\text{Profit or loss} = I - (FC + VC)
\]

Where \( I \) = income, which is the number of units produced and sold times the selling price per unit. \( FC \), or fixed cost, and \( VC \) or variable cost, when summed, represent the total cost of production. When costs are subtracted from income, obviously we get an indication of the P or L. Then:

\[
\text{Break-even point} = FC/ SIU - VCU
\]

Where sales income per unit = SIU, variable cost per unit = VCU, and fixed costs = FC. Typically fixed costs are those costs which do not change regardless of volume, at least on a short term basis. Examples could include taxes, depreciation, administrative costs, rents, and clerical costs. Variable costs usually include raw materials and direct labor involved directly in the production of the product. Fixed costs are also sometimes referred to as burden costs directly associated with a given technological function. That is, it is quite common to allow some percentage of a work center cost as fixed or burden cost. Gray areas might be maintenance costs since it is often not clearly associated with only one product, or even with only one product line. Also maintenance costs do rise with increased output since machinery is being used up more quickly. For obvious reasons it may be treated as a fixed rather than a variable cost.

Using an example where fixed costs are $100.00 and variable cost per unit is $.50, and sales income per unit is $1.00, break even point (BEP) can be calculated as follows:

\[
\text{BEP} = FC/ SIU - VCU
\]

Based on values given in the example, the break even point is 200 units or $200.00. Related to this, profit or loss (P/L) for a production quantity of 300 units under the conditions already given is found by:

\[
\text{P/L} = I - (FC+VC)
\]

\[
\text{P/L} = $300.00 - ($100.00 + $150.00)
\]

\[
\text{P/L} = $300.00 - $250.00
\]

\[
\text{P} = $50.00
\]

The production quantity of 300 units will provide a profit of $50.00. The break even point and various profit and loss levels are shown in the figure below. Explaining the break even graphical analysis, it must

realized that the fixed cost line is always shown as a horizontal line which is struck at the point in dollars off of the vertical side. Regarding both the vertical and the horizontal portions of the graph, it is important to always have equal graduations determined and laid out. This will enable a 45 degree angled line to be struck, always going through the break even point. If the variable cost line is struck from the point where the fixed cost and the vertical line meet, and run through the break even point, the graph is done. With appropriate labels shown, a useful graphical analysis of the technological circumstances will be created. This provides a tool for quick and efficient analysis, a useful presentation device and a method for communication.

Break even analysis can also be used to aid in determining which machine should be used to most efficiently produce a part. For example if a standard vertical mill and a computerized numerical control both are available for producing a job-lot of 100 pieces, which machine should be used? In this case.
special tooling (programming) is needed on the CNC machine, totaling $100.00:

\[ \text{BEP} = \frac{C1}{C2-C3} \]

Where C1 is the special tooling cost, C2 is the cost of machining on the lower production machine and C3 is the cost of machining on the higher production machine. If each part takes 30 minutes at $10.00 (labor/overhead) per hour on the conventional machine and 15 minutes at $15.00 (labor/overhead) per hour on the CNC machine, then:

\[ \text{BEP} = \frac{100.00}{(30/60 \times 10.00)} - (15/60 \times 15.00) \]
\[ \text{BEP} = \frac{100.00}{5.00} - (3.75) \]
\[ \text{BEP} = 80 \text{ units} \]

Since 100 pieces are to be run it would be cost effective to use the CNC mill under these conditions. If the lot size was at or below the break even point of 80, the CNC mill would not prove cost effective.

**Capital Investment Analysis**

Another cost analysis tool which should be studied is related to capital investment. This area is becoming increasingly important since moneys for investment and expansion must be used very prudently. It is quite likely that individuals studying this information will be involved in the justification and decision making for new equipment. Typical capital investment approaches used in technological organizations include depreciation, rate of return, return on investment, present value, and others.

The declining balance depreciation method, reviewed below, is particularly well suited to technological organizations where expected machinery life is typically from eight to ten years.

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<th>X</th>
<th>DECLINING BAL.</th>
<th>= DEPRECIATION</th>
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<td>8</td>
<td>20%</td>
<td>1</td>
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Declining Balance Depreciation.

Other depreciation methods may be equally as useful in circumstances where machine life may be longer or shorter than the life of production machines. Further analyzing the equipment under study with return on investment (ROI) cost analysis tools, the cost effectiveness of the machine or process can be better determined and compared to other processes/machines (perhaps the one currently in use or new machine being considered for purchase).

Given the circumstances noted in a subsequent example/table, salvage value = $176.16, based on subtracting the final depreciation value from the final year's declining balance. The basic ROI includes a technical description of the new process, cost justification statement, shipping and installation costs, depreciation and the ROI table as given in the example. The technical description would include pertinent information about the equipment's specifications and capabilities while the cash inflow would relate the proposed equipment to the current process and provide cost and time comparison in labor and scrap cost savings. Cash inflow, ultimately, however, does provide a cost value which represents a gain of the old equipment versus the new. For example, if we were considering a new press brake automatic fixturing system, to be used on a construction site or in a manufacturing environment, it might be provided as follows.

**Technical Description.** The automatic fixturing system will attach directly to the exiting press brake used in production, and remains as a manual system. Total cost of the system is $1,050.00 including shipping, setup and training from vendor. The vendor will supply within 30 days of order placement. The fixture will be bolted in position and is designed to enhance quality and productivity by enabling the operator to more quickly and precisely position work within the press. It is also noteworthy that reports from users researched indicated that lost time accidents were reduced due to the use of the fixture.

**Cash Inflow.** The new fixture will reduce the time in positioning parts by the operator by approximately 2 seconds per part loaded X an estimated 1800 parts per week providing 3600 seconds saved per week, or 60 minutes. This is one hour of labor @ $10.00 per hour X the 35 weeks estimated to use the press. Total labor savings provides $350.00. It is also estimated that the new fixture will reduce the current scrap and reject rate of 200 parts to a lower level of 100 parts per week. Since each part has an actual value of .10 at this point in production, it is estimated that 100 parts X .10 will result in a savings of $10.00 per week or $350.00 over the 35 weeks of the program. This provides a scrap and reject savings of $350.00.
Summarizing the cash inflow:

1. Labor savings = $350.00
2. Scrap and reject savings = $350.00
3. Total estimated cash inflow = $700.00

The basis for the projected/estimated cash inflow savings were (1) demonstrations on site at the vendor's location; (2) actual installed applications of a demonstrator on our site for a trial period of one month; and, (3) discussions with three current customers/users of the fixture provided by the vendor. It should also be underscored that all estimates provided are conservative, and the total basis was one part program which is, of course, expected to remain firm and possibly even expand beyond 35 weeks per year. Assuming greater savings can be realized beyond the current projections, and additional product or programs can be realized beyond the 35 weeks, this cash inflow projection can be enhanced.

Actual cost analysis procedures for the more complex ROI method presented are:

1. Determine and list cash inflow (CI). This is typically a dollar figure arrived at because the new process will be more efficient when comparing capability per hour (scrap percentage, accuracy etc.) to the old machine or process. If there is no old machine to compare the new proposed machine to, estimates of performance must be established for comparison.
2. Working across the table from left to right, subtract depreciation calculated from cash inflow (declining balance method).
3. Determine income taxes on inflow after depreciation, arriving at inflow after taxes. Typical taxes are around 50% as shown.
4. Subtract inflow after taxes from cash inflow, determining adjusted annual inflow. First year only of adjusted inflow, the federal government traditionally has given a 10% tax incentive of the initial total cost (ITC), which is then added to the first year adjusted inflow.
5. Divide the first year adjusted inflow by the initial total cost to arrive at the first year ROI and repeat for subsequent years. First year ROI is often the most critical since many industries may wish to pay off some minimum percentage in the first year (50% is typical) to remain competitive, as shown in the table.

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<th>50 % AF/TAX</th>
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Initial Total Cost (ITC) = $1050.00 ROI = 53.3%

Return On Investment.

ITC of new equipment was $1050.00, depreciation rate 30%, and a first year tax incentive of 10% was applied. When first year adjusted cash inflow was divided into ITC the result was a first year 53.3% return on investment, likely providing a sufficient payback under conditions noted.

A possible alternative used to give a quick glimpse at potential cost and payback relationships would be to simply divide the cash inflow for one year by the initial total costs. Sometimes referred to as a simple payback calculation this would be:

\[
CI / ITC = PB
\]

where ITC is initial total cost, CI is cash inflow and PB is payback in percent. Using previous values:

\[
$700.00 / $1050.00 = 61% 
\]

Each time this program was run under conditions noted, it would result in these cost savings and payback, paying for itself in less than two years. Simpler payback methods do not give all financial accounting advantages and inputs.

It must also be stated that neither approach provides a realistic factor for present or future value of money, assuming inflation or deflation occurs in the actual value of money in the economy, as it most certainly will. This relates to interest rates and other financial issues which may be important in the broader organizational sense, but are thought to be beyond the current discussion. Much of this approach to cost analysis, while financial and accounting in basis, relates to the way taxes are paid and overall equipment and capital investments and assets are shown with the federal government.

The simpler payback alternative offers the major advantage of being relatively quick and easy to perform and understand, particularly appropriate to
applications engineering decision making circumstances. This should prove useful for technologists and others wishing to quickly calculate potential costs savings in proposed technological upgrades. Both the ROI method and the simpler payback approach offer useful analytical cost tools which should be practiced and applied by technologists and others when trying to determine solutions to proposed upgrades.

Materials Requirements Planning, Costs, Work In Process, Line Balancing

Several inventory and materials management tools are introduced as related to cost control in the current tool. Those reviewed include procurement costs, carrying costs, total incremental costs, economic order quantities, reorder point and general materials requirements planning (MRP). It should be pointed out, similar to many of the other costs issues and tools, that this area is another fairly complex area. This section provides merely a start, and should not be misconstrued as anything more than an introduction. Yet much opportunity is provided for cost reduction and/or control though the application of these tools. Further study and analysis of information should be pursued by interested persons.

Beyond specific inventory issues associated with the cost items identified above, there are other issues which are introduced and reinforced in this section, and followed up in later tools and sections. This has to do with scheduling and line balancing at the work area level, as well as beyond, both in micro and macro ways. The concept of work in process, or WIP, is part of what we wish to reduce, providing potential savings in inventory dollars. By better understanding the processing functions, and by analyzing methods and time relationships, we can also enhance the work flow of product, and reduce WIP related inventory costs due to inefficiencies.

Procurement. Procurement is the first area explored since it relates to obtaining materials and components for production. Typical concerns with procurement costs are clerical people and time to process an order, time involved to accurately communicate specifications, quantities and other critical information both in plant or on a job site by warehouse personnel, production managers, and others, and time involved in actually obtaining the materials and components. Procurement costs are determined by:

\[ P = \frac{R}{Q} (S) \]

Where \( P \) is procurement costs, \( R \) is annual requirements, \( Q \) is lot size of the quantity ordered, and \( S \) is order cost per order (generally clerical in nature), and \( R/Q \) is the number of orders per year. An example order of 200 units, annual requirements of 1000 units, and a order cost of $20.00, shows:

\[
P = \frac{1000}{200} (20.00)
\]

\[
P = 5 (20.00)
\]

\[
P = 100.00
\]

And with an increase in order size to 500 units:

\[
P = \frac{1000}{500} (20.00)
\]

\[
P = 2 (20.00)
\]

\[
P = 40.00
\]

The larger the order, at least in a simplistic sense, the lower the overall procurement costs. This assumes annual requirements remained constant and larger order quantities can be tolerated. Part of what is in conflict with this is the trend toward smaller lots shipped more frequently for just in time production. When smaller shipments for various products and components are all lumped together, it is assumed that a sufficient critical mass for economic transport costs may be achievable, thus enabling the small lot size shipped more frequently to match reduced inventory in the warehouse. Ideally, inventory should be in transit rather than sitting idly, warehoused.

Carrying costs. Related to procurement costs, carrying costs have to do with costs of keeping materials or components in stock (or in production, in process), recognizing that the inventory is costing the organization the entire time they are in their’s. Carrying costs can be determined with the formula:

\[ CC = \frac{Q}{2} (C) \]

Where \( CC \) is carrying cost (typically for the year), \( Q \) is the maximum demand generally required based on the history of the overall system, \( C \) is the carrying cost per unit (warehouse rental, internal clerical functions to track, and so on), and \( Q/2 \) is the average inventory level at any given moment in time. Using figures applied in the previous example and the value $.16 as the carrying cost per unit:

\[
CC = \frac{1000}{2} (.16)
\]

\[
CC = 500 (.16)
\]

\[
CC = $80.00
\]
**Total incremental costs.** When procurement and carrying costs are added together it is traditionally called total incremental costs. This then reflects an additional component of inventory costs to be studied, and is determined through the use of the formula:

\[ E = \frac{Q}{2} (C) + \frac{R}{Q} (S) \]

Therefore using the values and nomenclature previously presented to solve for total incremental costs:

\[ E = \$80.00 + \$40.00 \]
\[ E = \$120.00 \]

Total incremental costs, or carrying costs added to the procurement costs, are $120.00 under the conditions presented. Based on this determination we can now begin to determine where potential costs savings might be located in the overall technology system related to inventorying materials and components.

**Economic order quantity.** Another key inventory function presented here is the economic order quantity (EOQ). EOQ is useful for knowing actual optimum levels required for orders related to the broader system, and is determined by the formula:

\[ EOQ = \frac{2RS}{C} \]

Using values and nomenclature previously presented, where R was an annual requirement of 1000 units, S was an ordering cost of $20.00 per order, and C was a carrying cost per unit of $.16 we can conclude:

\[ EOQ = \frac{(2)(1000)(20.00)}{.16} \]
\[ EOQ = 250,000 \]
\[ EOQ = 500 \text{ units} \]

The EOQ takes into account annual requirements, ordering and carrying costs, and attempts to help determine a reasonable level of units to order in each shipment. Again this must be tempered with other information and requirements of the overall system, and can not be relied on as an end all answer. But when used in the context of transport costs both in and out of the organization, and when viewed alongside the realities of possible labor costs accrued with no useful productive output if nor materials or components are available for production, we begin to understand the need to careful and thorough planning.

**Reorder point.** Related to the broader system, reorder point attempts to determine the most cost effective point in time for reordering, and the number of units at which to replenish the supply, using:

\[ RP = (U) \left( \frac{t}{T} \right) + m \]

This formula applies where U is a use rate value determined over time, through experience or calculated similar to the way we are doing here using a sub formula of \((M - m)/T\). This assumes that M is a maximum planned inventory level, m is a minimum planned inventory level, and T is time the supply will last. Small m is used twice in the total calculation and small t is the lead time required to obtain materials or components after they are ordered, obviously relating to shipping and transport issues.

Determining reorder point in the case of a maximum inventory level of 700 units, minimum inventory level of 100 units, time supply will last of 30 days, and lead time to obtain new order (lead time) of 10 days, a calculation could be performed as:

\[ RP = (U) \frac{t}{T} + m \]
\[ U = \frac{(M - m)}{T} \]
\[ U = \frac{(700 - 100)}{30} \]
\[ U = 600/30 \]
\[ U = 20 \]

And inserting \(U = 20\) into the broader formula to solve for \(RP\),

\[ RP = (20) \left( \frac{10}{30} \right) + 100 \]
\[ RP = 200 + 100 \]
\[ RP = 300 \]

Reorder point, 300 units, is also shown schematically, along with minimum and maximum levels and other information in the MRP analysis calculation.

**Cycle time, safety stock.** The additional information shown previously as minimum and maximum levels within the broader context of inventory costs is related to the total consumption of the inventoried units. This provides a broader picture of inventory and production relationships, termed cycle time, and the necessary quantity to keep available at any given time, called safety stock. Cycle time is associated with the time required to consume the inventory given fixed and predictable rates of production. Safety stock is associated with a minimum level of inventories which provides some
cushion for assuring we can build product, but should be minimized for holding costs down. In this case safety stock and minimum inventory level are the same, although it is not necessarily always this way. The form, with all inventory functions for analysis, is provided in the applications section. The form relates all traditional inventory cost functions as discussed in this section for potential savings and improvements.

**MRP, materials requirements planning.** Materials requirements planning (MRP) is a system related to inventory analysis which is useful to technological systems' managers for obtaining optimum productivity and reduced operating costs as related to materials and labor within the overall system. MRP permits managers to accurately plan materials needs functions, thus working to capacity. Although frequently done by computer, particularly in the case of complex production functions, the concept can be useful in all technological systems (computerized or not). MRP systems simply analyze how many parts are needed for each subassembly in a product and determine where and when they will be needed in the broader system and sequence.

A product requiring parts and subassemblies shown in the following listing is provided. Product A consists of two subassemblies, B and C, in a total of six units required. These subassemblies require four parts, C, D, E and F, requiring thirty six units.

<table>
<thead>
<tr>
<th>Product A</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subassy B</td>
<td>2</td>
</tr>
<tr>
<td>Subassy C</td>
<td>4</td>
</tr>
<tr>
<td>Part D</td>
<td>14</td>
</tr>
<tr>
<td>Part E</td>
<td>6</td>
</tr>
<tr>
<td>Part F</td>
<td>4</td>
</tr>
<tr>
<td>Part G</td>
<td>12</td>
</tr>
</tbody>
</table>

Product A MRP Analysis Tree.

While the simplistic example shown may underestimate the complexities in production and inventory relationships, it does open doors to scheduling, balancing and routing issues which are essential to broader improvements and potential cost savings based on MRP analysis. These relationships can be further studied and potential opportunities isolated, through the use of a Gannt type chart. The chart, identified as the MRP planning form, is illustrated based on the example of product A, shown nearby. This form is based on product analysis tree generated earlier, and considers a time managed flow of product and components required for production.

Thus, if an order for 10 units of product A must be filled, then the material requirements will be 20 B subassy units and 40 subassy units. The material requirements are then placed on a planning chart as shown in the figure. As indicated in the MRP plan, ten units of Product A have been ordered on day one. As well, however, 40 units of item C had to be ordered or produced to meet the production demands, beginning on day one. Other components and/or subassemblies were similarly planned for, and ordered, to meet demands of the system. If the plan is worked to completion, it constitutes backwards planning to facilitate maximizing each workstation through reduced work in process (WIP) and still having sufficient materials to enable production.

**Line balancing for waste reduction, cost efficiency.** Part of what the current section is about is related to line balancing. This also ties together a previous section, and the entire tool, by bringing process analysis, time study, MRP issues and WIP together. This is all driven by our need to address line balancing as a function of a well balanced production process. The basic assumption is that costs can be minimized as a function of waste reduction and optimum efficiency at the point of production. The various SOP and TAKT analysis forms also can assist in line balancing analysis to provide a complimentary form of documentation, consistent with other systems presented throughout the toolkit. The forms also provide mechanisms for
further analysis and assessment of variables associated with balancing the production function. This includes distance, time, people, cycle times, WIP levels, units actually produced at each location, among others. All categories are intended to provide opportunities for cost reductions and productivity improvements based on a smoother production function.