Operational Model for Improving System Productivity of Distributors: Internal Cost Drivers

Research

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1. Executive Summary

Distribution in specialty contracting is facing a fork in the road in its role in the supply channel. It can continue to play its historical role of wholesale/retail combination of parts pass through and hope to be profitable through speculations, or it can become a low cost provider of services and products by managing the channel.

This segment of the research concentrates on identification of cost drivers for distributors. The examples in this segment will be focused on Electrical Distribution. The principles, however, apply to all specialty contractor distribution channels.

The cost drivers (CDs) are divided into three categories: CD by customer, suppliers and internal. This study further concentrates on three focus areas of their CDs:

1. First-time pass yield of order taking and delivery
2. Identification and reduction of waste
3. Customer point of order entry

The three focus points will identify and eliminate waste driven by internal inefficiencies, customer miss ordering, and supplier's impact on price and delivery. Every business needs to be profitable to survive. Profitability can only come through system productivity. Productivity depends on recognition and elimination of waste in the current process of operations. Further system productivity can be achieved by operation process innovation.

Distributors can improve their bottom line by better than 30% by following the waste reduction methodology suggested in this paper. Improving the first time pass yield, inventory turns, and customer order entry point will be the key to increased productivity.

2. Introduction

The distributor's profits in their historical operation mode of conduit in the distribution channel are strongly dependent on local and national economy. Neglecting the accidental windfalls, the overall profitability of the distribution industry is eroding.

This research is set out to identify the cost drivers, which consume the majority of the profits of the distributors. Issues such as pricing models and their impact will not be addressed in this research. We believe that pricing model is the by-product of operational model, which if not designed and understood correctly will have a major impact on cost structure and therefore the profitability. Pricing model becomes important when the internal cost drivers (CDs) are not well understood. The reader will be introduced to:

1. System Productivity
2. Order taking and delivery first time pass yield
3. Application of six-sigma throughput to reduce waste
4. Customer point of order entry to reduce error
5. Models and forms for identifying and reducing waste

3. System Productivity

Aristotle once said, "The whole is more than the sum of its parts," when describing a system. This statement is the basic premise of any system. A change to one part of the system is going to affect another part of the system.

Productivity is defined by production output per unit of effort. It can also be defined by the effectiveness with which labor and equipment are utilized. System productivity concentrates on the best utilization of all the resources, which will enable the entity to use their assets in a most effective way.

Productivity of the system is the result of improvements in: Valueless time, variance and activities. Figure 1 is depicting the improvement impact of each one of the productivity drivers on the entire system. Reduction of valueless time will reduce the time to detect and improve the time to correct, which will reduce the defects and errors and reduce the system cycle time. This will lead into a faster response and higher quality (value) for the customer. Improvement in valueless variance and activity will reduce expediting, transaction cost, inspection and carried inventories. This will lead into lower overall operation cost and improve the quality and value to the customer. Later in this report we will discuss the impact of improvement in customer's point of order entry and its impact on time to detect and time to react.

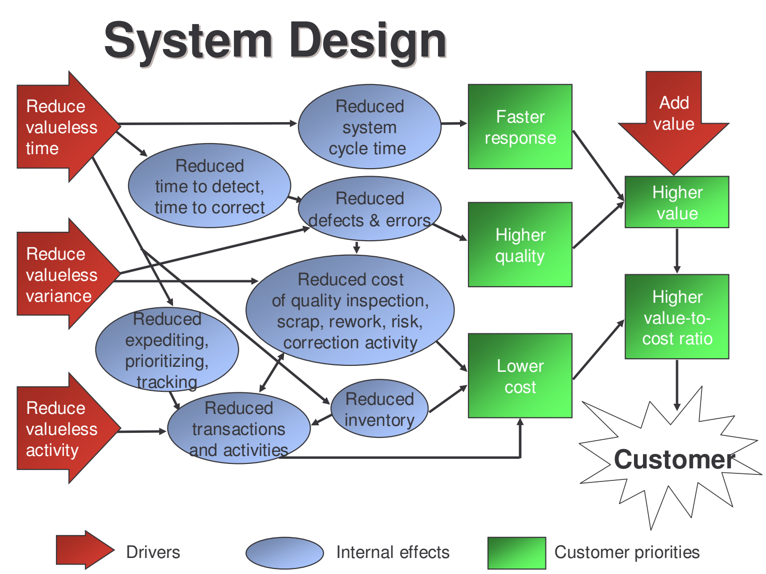


Figure 1. System design diagram

4. Order taking and delivery first time pass yield

First time pass yield is defined as the amount of satisfactory material available after the completion of a given operation processes expressed as a percentage of the total amount produced. In other words, the first time pass yield is the quantity of products that a system can produce without errors at the end of the process as a percentage of total production. Every error during the process will reduce the first time pass yield. The longer the error produced in one-station proceeds in the process undetected, the higher is the cost of recovery and error proofing. The cost of rework is therefore directly related to the time and location of the error detection. The more stations that will be involved in reworking the error, which is discovered in the later stages of the process, the higher will be the cost of rework. Figure 2 shows the schematic of error processing in a multi-stage production.

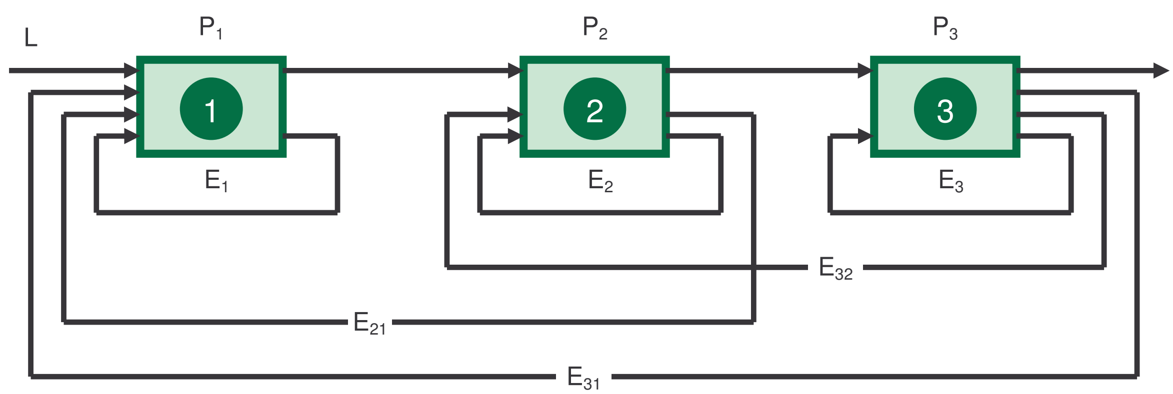


Figure 2. Error processing in a multi-stage production

The error identified early in the process, has less impact on the overall cost of production. On the other hand if an error made by step one is identified at step three it will carry a higher cost for its correction. Error discovered at step 3 could have been caused by step three itself (E_3), or by step two (E_{32}) or at the beginning of the process at step 1, E_{31}. As the rework loop becomes larger, the cost of rework escalates.

We will try to illustrate the cost of late error detection with an example. Assume a distributor has a 7-step order fulfillment process. We also will assume that each step cost \$10 to complete as shown in Figure 3. The cost of each step could be attributed to resources such as labor, fuel, paper, printer toner, vehicle wear & tear, tape, boxes, and any other resource that may be used in a step of the process. If the distributor is able to successfully fill a line item on the first time pass in this process, the process would cost $70 to complete. Any error in this process would add additional cost due to the added rework.

Figure 3. Cost of error-free production = $70

Whenever an error occurs, rework follows. A simple rework loop occurs when for example a picking error is identified in inspection see Figure 4. The wrong part was picked from inventory and inspection identified the error. The inspector notified the worker who picked the wrong part. The worker then had to restock the wrong part, pick the correct part, and then take it to inspection. The inspector then inspected the new part and approved the line item.

The cost of rework is at least three-fold:

1. Cost of performing steps of the process in error the first time through the system.
2. Cost to fix the error including repeated steps (picking & inspecting) and additional steps (restocking).
3. Cost of opportunity that was lost while spending time fixing the error. This is referred to as "Lost Opportunity Cost".

This is referred to as the "Rule of 3". Every error that occurs cost at least 3 times to correct. The actual cost of errors for distributors could be as high as 5 to 6 times the original cost to process the order due to the extra steps involved in resolving an error. In this example, two steps that cost $20 on the first time pass instead cost $80 after the rework loop occurs to fix the error.

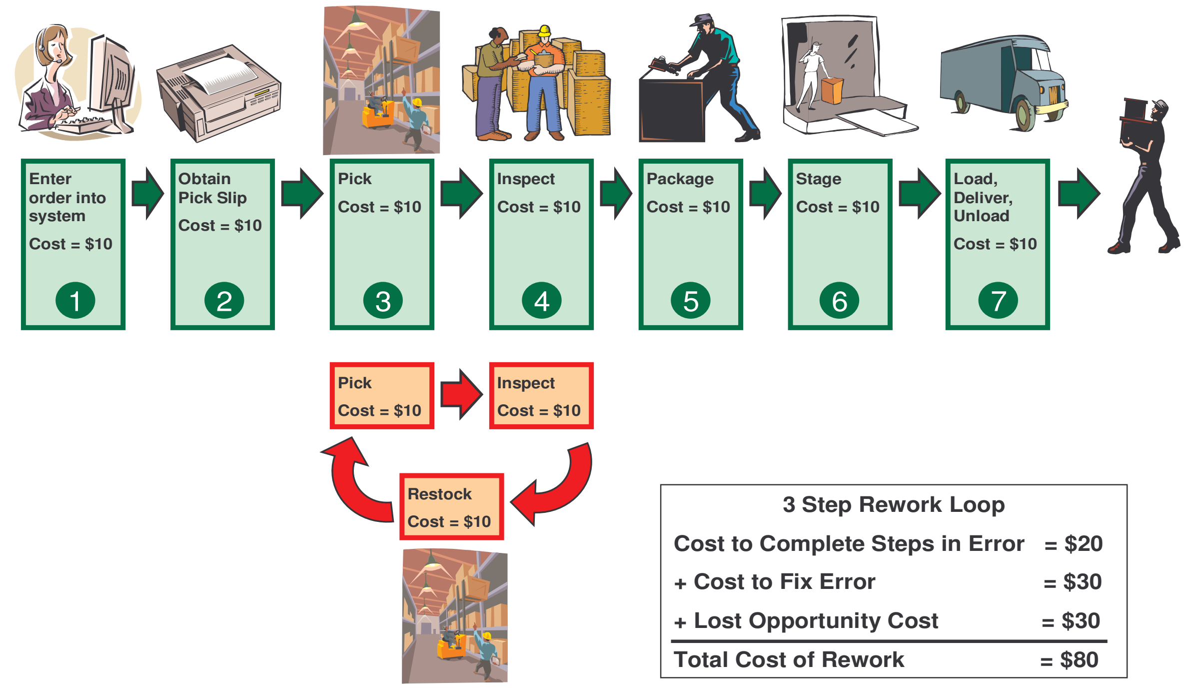


Figure 4. Single rework loop due to local error detection

If an order is filled with an error on one of the line items, and it is not recognized until the customer examines the order, a major rework loop will follow. Figure 5, shows a possible rework loop when the customer identifies an error. Here the labor picks the line item in error. He then loads the item onto the truck and returns it to the warehouse where it is unloaded and placed in temporary storage to be restocked. The appropriate paperwork is completed for returning material and the corrected line item is sent through the order fulfillment process once again. On the first time pass this line item cost $70 to fill and required 7 steps to complete. As a result of the error, the process has ballooned to 18 steps and cost $290 to complete (taking into account the cost to fix the error and the lost opportunity cost.) An error may also cause customer satisfaction to decline, ultimately causing loss of business.

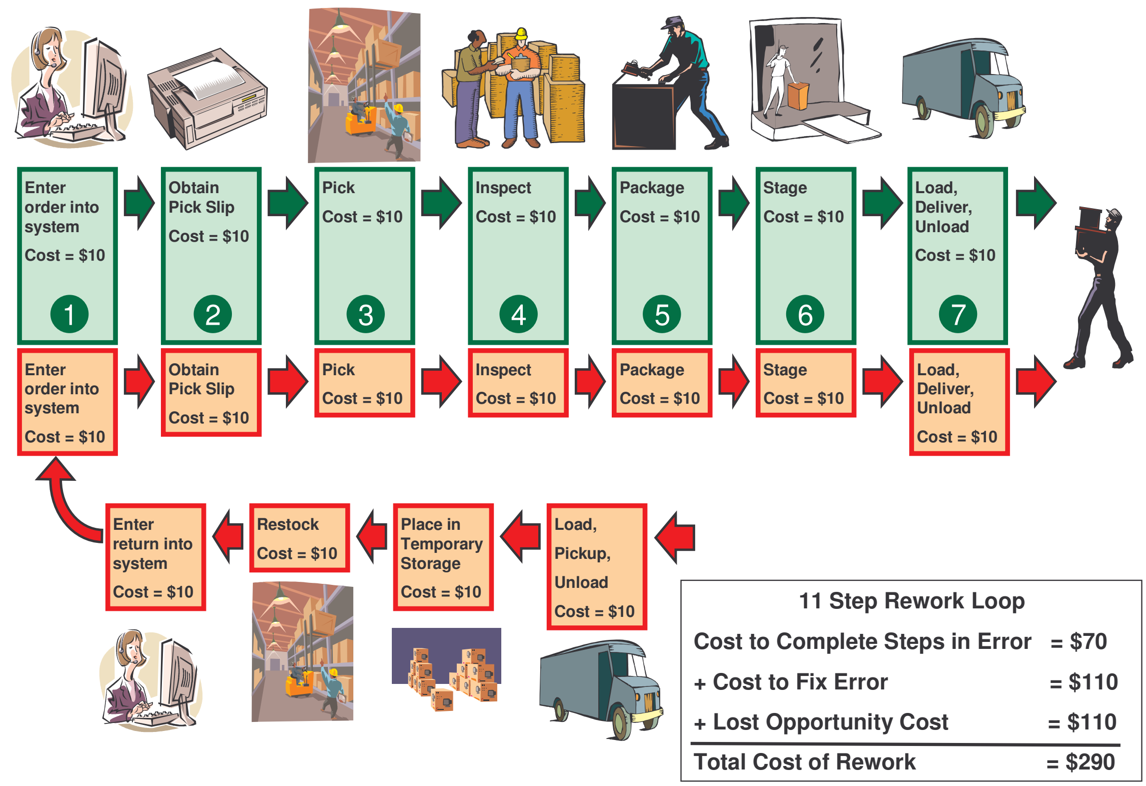


Figure 5. Total cost of error detection by the customer

5. Application of efficiency throughput to reduce waste

In order to further explore the internal cost drivers and their impact on distributor's profitability, it is necessary to explain various production levels first time passes measurement method.

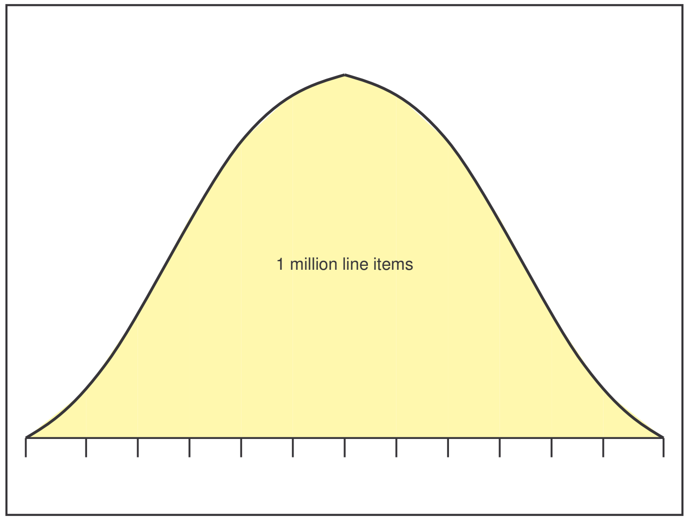


Figure 6. Normal distribution of one million line items processed during a year

The accuracy of the error-free process is measured by the acceptable final output's standard deviations. In other words, what is the percentage of error-free line items produced compared with the total production. Output rate of one standard deviation would mean first time pass of 67%. Where an output rate of six-sigma would have 99.99966% correct first time pass of error free line item.

To determine a distributor's operation sigma level, we need to know the total line items produced over a time period. To illustrate we will assume that a distributor has worked on one million line items of various sizes and cost in a year. The normal distribution of the line items is shown in Figure 6.

The accuracy of the order and its variance will be measured by the percent of correct line items on acceptable orders and the standard deviation of that percent from the mean percent correct of all the orders.

If one million line items are filled, and 900,000 of them were processed accurately, the number of line items filled erroneously is 100,000. This would be an accuracy rate of 90%. This accuracy rate falls between 1 sigma, 68.27%, and 2-sigma, 95.45%, according to the chart. Therefore, this operation is said to be operating between 1 sigma and 2-sigma.

Improvement in a distributors operation from 1 sigma to 3-sigma will result in 314,611 fewer errors per million line items. Applying these ratios to the two examples given in section 4 will result in an estimated $25,168,880 to $91,237,190 cost reduction in operations by improving from one-sigma to three-sigma (see table 1).

Table 1. Cost reduction in operations by improving from one-sigma operation to three-sigma

Line Item Errors at 1s =	**317,311**
Line Item Errors at 3s =	**2,700**
Difference in Line Item Errors = **(Line Item Errors at 1s – Line Item Errors at 3s)**	**314,611**
Low-End Cost Reduction = **(Difference in Line Item Errors X $80 per Low Cost Error)**	**$25,168,880**
High-End Cost Reduction = **(Different in Line Item Errors X $290 per High Cost Error)**	**$91,237,190**

5.1. Calculation of first time pass yield (FTPY)

We will use a three-step process to illustrate the calculation methodology for the first time pass yield. Figure 7 shows a three-step process and possible rework loops.

Nomenclature definition:

L = # of line items entering the system

P = # of line items produced on first time pass

P_X = # of line items produced on first time pass at step X.

E = # of line items that have errors

E_X = # of line items that have errors at step X. These errors are fixed at the same step where they occurred.

E_{XY} = # of line items that have errors at step X and must be returned to step Y.

C = maximum system capacity

C_X = maximum capacity of the step X.

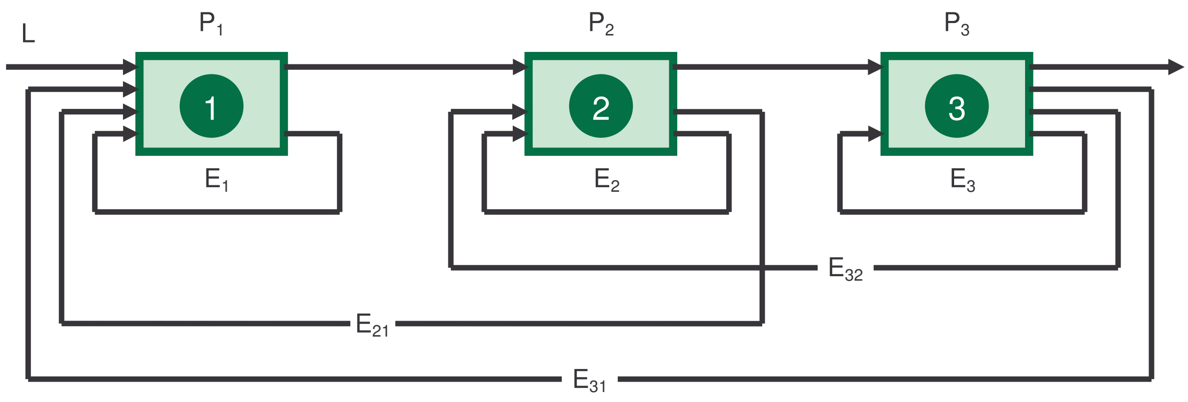


Figure 7. A three-step process with error and rework

The number of line items entering the system (L) and the number of errors at each step in the process (E) are measured values, which can be tracked. The number of error free line items (P) for each step is calculated by subtracting E from L. Equation 1 shows this calculation for step one in the process. P1 is the First Time Pass Yield of the step one. This equation is depicted schematically in Figure 8.

Equation 1. First Time Pass Yield of step one

$$P_1 = L - E_1$$

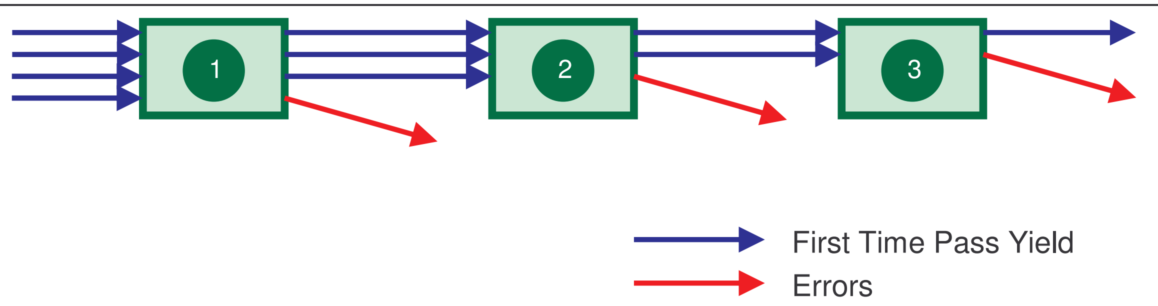


Figure 8. First Time Pass Yield of steps one, two, and three.

In order to determine the first time pass yield of the system, the first time pass yield of each step must be calculated. The error-free line items produced in step 1 (P1) will be used as the input for step 2. The first time pass yield for step 2 (P2) is the number of error-free line items (P1) entering step 2 less the errors (E2) made in step 2 and less the errors made in step one and discovered in step tow (E21) as shown in equation 2:

Equation 2. First Time Pass Yield production of step two

$$P_2 = P_1 - E_2 - E_{21}$$

The same method is used to calculate the first time pass yield of the remaining steps in the process. Figure 8 is helpful for visualizing the first time passes of each step. The total first time pass yield of the system is the sum of the first time pass yield of each step (Equations set 3).

Equation 3. First Time Passes of all steps in the entire process

$$P_3 = P_2 - E_3 - E_{32} - E_{31}$$

$$P_4 = P_3 - E_4 - E_{43} - E_{42} - E_{41}$$

$$P_5 = P_4 - E_5 - E_{54} - E_{53} - E_{52} - E_{51}$$

$$P_X = P_{X-1} - E_X - E_{X(X-1)} - E_{X(X-2)} - \ldots E_{X2} - E_{X1}$$

We now need to calculate the capacity of the system. The *capacity* (C) is the total line items being worked on throughout the process. This includes both the error-free line items and the reworked line items. The capacity of the system is the sum of the capacities of each step.

The capacity of step 1 (C1) is the total out put of

1) First time pass output P1 plus
2) Line items with errors from each step in the system that must be reworked at step 1.

Equation 4 shows the calculation of needed capacity in step 1 of a system with X number of steps is:

Equation 4. Capacity needed in step one in a multi-step production

$$C_1 = L + E_1 + E_{21} + E_{31} + E_{41} + \ldots E_{X1}$$

The capacity of each remaining steps in the system is the total output of

1) First time pass yield of that step and
2) Line items with errors from each step in the system that must reworked at the step in question.

The equations for the capacity of the remaining steps of a system with X number of steps is shown are equation sets 5:

Equation 5. Calculation of the capacities needed in each step of the process

$$C_2 = P_2 + E_2 + E_{32} + E_{42} + E_{52} + E_{62} + \ldots E_{X2}$$

$$C_3 = P_3 + E_3 + E_{43} + E_{53} + E_{63} + \ldots E_{X3}$$

$$C_4 = P_4 + E_4 + E_{54} + E_{64} + \ldots E_{X4}$$

$$C_Y = P_Y + E_Y + E_{(Y+1)Y} + E_{(Y+2)Y} + \ldots E_{XY}$$

We will now try to demonstrate the first time pass and capacity calculations of a system on hand of the following example:

Example 1 - First Time Pass Yield

Known:

Order fulfillment is a 2-step process.

100 line items enter the order fulfillment process: L = 100

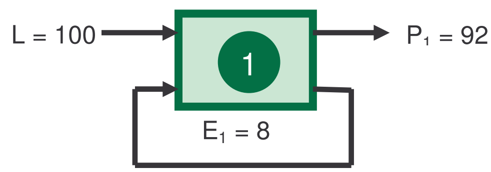
Step 1 yielded 8 errors: $E_1 = 8$

Step 2 yielded 6 errors that were returned to step 2: $E_2 = 6$

Step 2 yielded 4 errors that were returned to step 1: $E_{21} = 4$

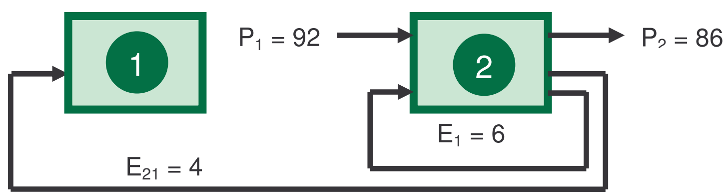
First time pass production for the first step is:

$$P_1 = L - E_1$$
$$P_1 = 100 - 8$$
$$P_1 = 92$$



92 first time pass line items then enter into step 2. First time pass production for the second step is:

$$P_2 = P_1 - E_2 - E_{21}$$
$$P_2 = 92 - 6$$
$$P_2 = 86$$



The total first time pass yield (P) of the system is the first time pass yield of the final step. For this example system first time pass P is equal:

$$P = P_2 = 86$$

The first time pass yield will be expressed as a percentage of total line items:

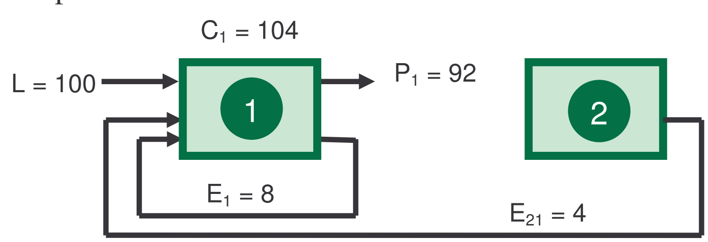
$$\text{First time pass yield \%} = \frac{P_2}{L} \times 100$$
$$\text{First time pass yield \%} = \frac{86}{100} \times 100$$
$$\text{First time pass yield \%} = 86\%$$

First time pass yield percentage is the percentage of error-free orders produced by the system and thus can be used to determine efficiency level, see Section X. A form for calculating first time pass yield can be found in Appendix X.

Example 2 – Capacity (C)

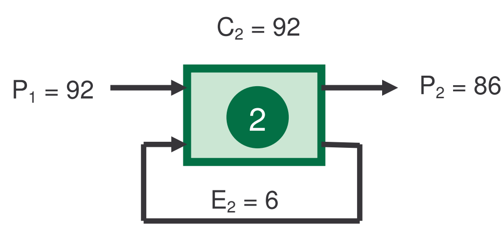
The capacity for this system is simply the total line items processed. Capacity is both the first time pass yield and rework that the process is producing. For this example, the capacity of step 1 is:

$$C_1 = P_1 + E_1 + E_{21}$$
$$C_1 = 92 + 8 + 4$$
$$C_1 = 104$$



The capacity of step 2 is:

$$C_2 = P_2 + E_2$$
$$C_2 = 86 + 6$$
$$C_2 = 92$$



First time pass yield and capacity can be used to identify the bottleneck steps in the process. These measures can also be used to benchmark current performance versus past performance to track improvement for all or part of a process. The combination of the error identification, first time pass yield and capacity calculation provides a tool for tracking the cumulative cost, time, and frequency of errors in the order fulfillment process.

5.2. Identification and Reduction of Waste

The additional cost incurred due to errors is the wastes in the system. It needs to be identified and eliminated. On hand of a graphically represented in Figure 9 we will try to expose the waste of the system. If the first time pass of order taking and delivery process is roughly at 67% (1σ), and we need to have an output of 100 line items, the system capacity has to be at 149 line items.

$$\frac{100 \text{ line items}}{x \text{ line items}} = \frac{67\%}{100\%}$$

$$x = \frac{100 * (100\%)}{67\%}$$

$$x = 149 \text{ line items}$$

If the system capacity is only at 120 (due to company's resource limitations and overhead cost) then the actual capability of the system is only 80 line items, reworked line items account for the remaining quantity that is required. The green line represents error free

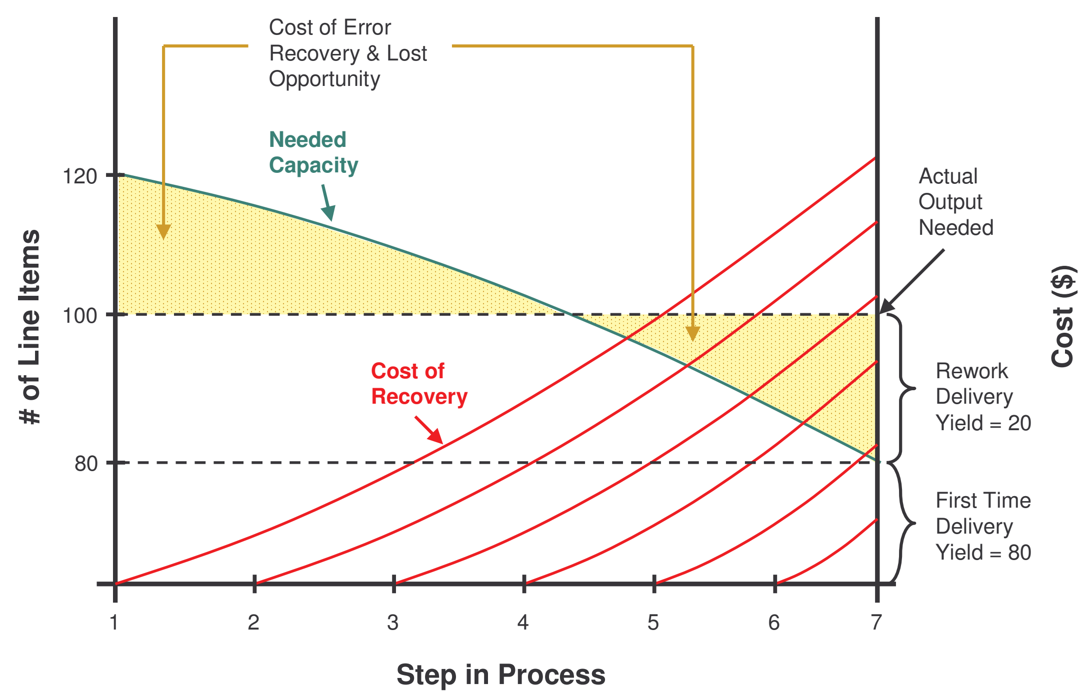


Figure 9. Overall capacity needed to produce the required line items

WIP (work in process) which will result in first time pass yield. The red lines represent cost of recovery when a line item is returned from step 7 to an earlier step in the process. If a line item is returned from step 7 to step 6 then the rework is minimal represented by the cost of recovery at step 6 in the figure. If a line item is returned from step 7 to step 1 then the rework is significantly greater because all 7 steps may have to be repeated.

Figures 10-12 show a breakdown of figure 9. Figure 10 depicts a production process that operates at 99.9996% first time pass. The cost of error (3.4 out of one million line items) is very minimal.

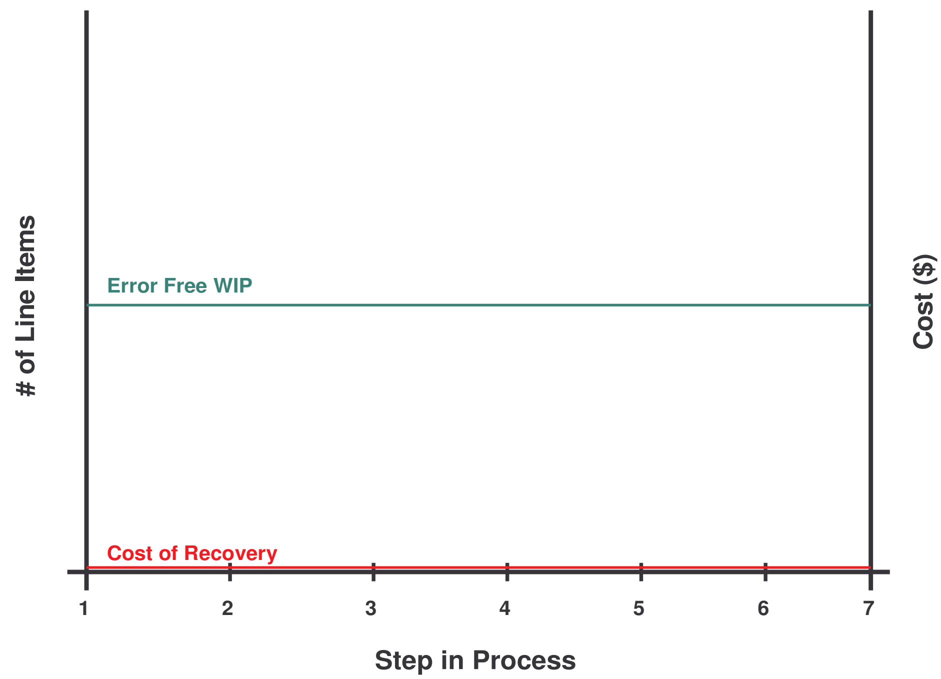


Figure 10. Error-free production at 99.9996% first time pass

The schematic of waste is depicted in figure 11 & 12. As the first time pass decreases to less than 99.9996% the cost of the operation increase. Slower the system responds to error and its recovery, the higher is the cost of waste. Figure 11 shows the capacity needed if the error detection and recovery is reducing the system's first time pass to 67%. Figure 12 on the other hand shows the cost of error recovery as the error detection happens further downstream.

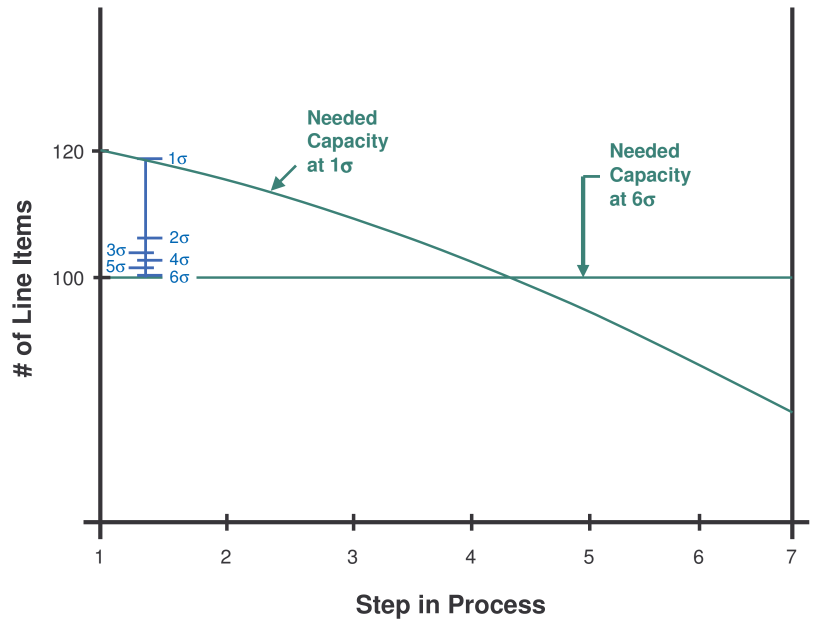


Figure 11. Capacity needs increase as the errors and rework increase

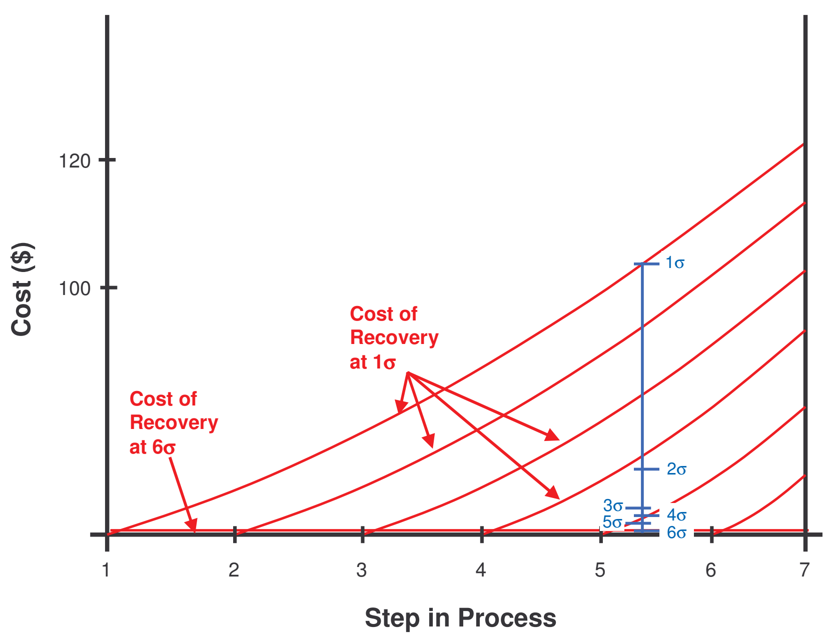


Figure 12. Cost of error recovery downstream

6. Customer Ordering Operation

Customers have driven the evolution of the distributor's operational model. Distributors in response to their customer's needs have adapted their processes over the years to provide their customers with the service they demand. This has resulted in building massive inventories to ensure that they can meet the same day/next day demands of their customers. Since the distributors have built their operational model around the concept of same day/next day service, customers rely on distributors to continue to provide them with what they need, when they need it. Customers do not need to plan ahead for the material they need. Instead, customers can call their local electrical distributor and have the material within a few hours.

This type of service is very costly. The overhead associated with next day service: carrying cost of inventory, capital allocated to inventory, zone warehousing, courier service, and other requirements necessary to meet these needs is one of the main cost drivers. Distributors are some times force to provide competitive pricing which often is less than the costs of operations. The average net profit of electrical distributors is merely 1.2% before taxes, and is declining each year.

Another issue is that customers will often order large quantities of material at the beginning of the project. Many times the orders will exceed what the customer actually needs to prevent starvation, earn bulk discounts, be prepared for change orders, and ensure material is not back ordered/out of stock when it is needed on site. At the end of the project or at the end of the fiscal year, customers return all the excess material that they have accumulated. This generates a surge of rework at the end of the year. Distributors experience an estimated 100% increase in returns in November and December.

6.1 Time to Detect & Time to React

Creating visibility for what is occurring in the order fulfillment process becomes especially useful when there is time to respond to customer orders. When an event occurs that will impact profitability of the order fulfillment process, such as finding an error in inspection or entering the wrong product into the system, there is a limited period of time within which the distributor can react and still remain profitable. This period of time is from time A to time C as shown in Figure 13. However, in order to respond to the event, the event must first be detected as an event that will impact profitability. The ***time to detect*** the event [in **Figure 13** time A to time B] has an influence on whether or not the ***time to react*** [in **Figure 13** time B to time D] occurs soon enough to respond so that profitability is still possible.

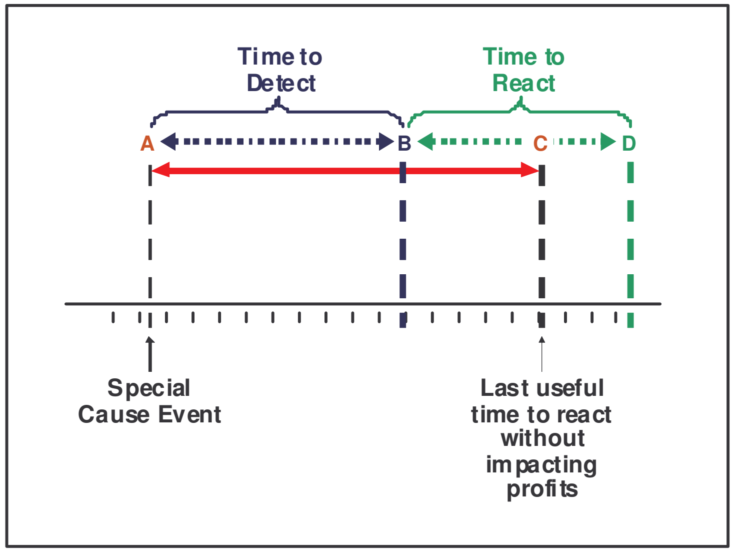


Figure 13. Schematic of customer's order entry point

Time to Detect can be influenced by:

- When you look for an order
- Who looks for an order
- What orders you are looking for
- Where you are looking for an where
- How you look for an order

Time to React can be influenced by what you have to react with including:

- Personnel
- Tools
- Schedule
- Materials
- Methods

As the ***time to detect*** [in **Figure 14** A-B] shrinks, the ***time to react*** [in **Figure 14** B-D] moves and expands, giving the operator more flexibility and options. The method used to detect customer's ordering habits will influence profits as a result of the method's impact on the time to react. It is useful to use a method that will see and signal customer's wish to order, such as information gathered by the truck driver to the people who can respond, in time for them to respond effectively.

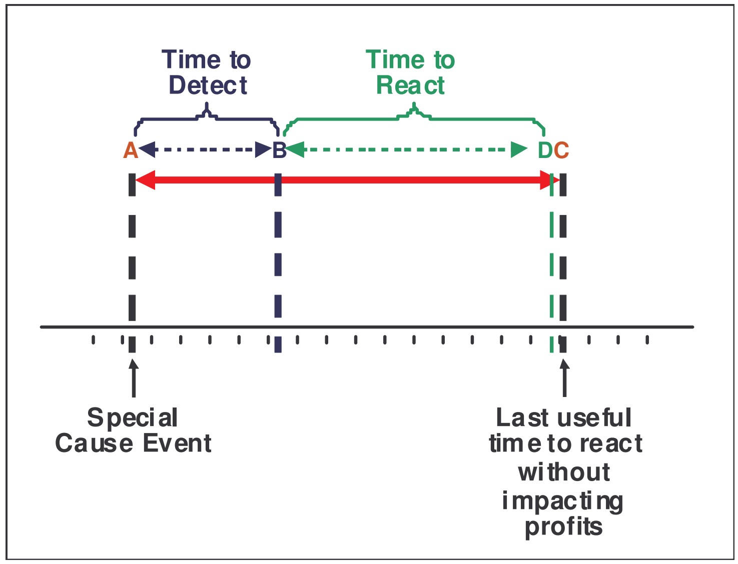


Figure 14. Order entry and ED's reaction time

The solution to these issues is not easy and will require innovative strategies. Education, incentives, and partnership are three methods, which may be used to confront these issues. The critical piece of educating the customer is to demonstrate measurable results when changing their ordering habits.

The distributor will need to work with their customers to define cost savings through measurements such as the customer's estimated labor hours vs. actual labor hours. Many hours are spent handling material on a construction site. By educating customers on how to manage material, their labor hours in material handling will decrease. This can be compared to estimated hours to determine the cost savings. Another measure is the carrying cost of material. If the carrying cost is 1% a month, then customers would lose money on material stored on the jobsite each month until it is installed.

Once customers find benefit in managing their material more efficiently, distributors can reduce their same day/next day deliveries and will be able to optimize inventory levels. The *economic ordering quantity* (EOQ) *model* shown in Figure 15, defines the optimal ordering quantity for distributors.

The optimum order quantity is when the cost of ordering and cost to carry inventory is minimized to the lowest possible value. EOQ can be calculated with the following equation.

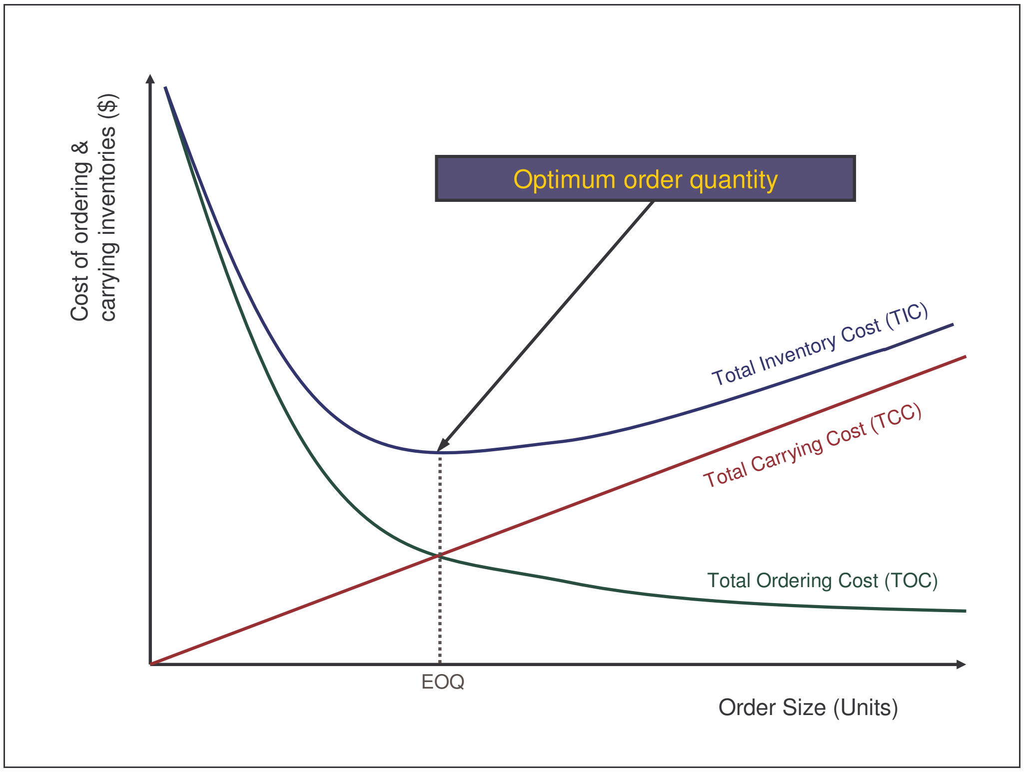


Figure 15. Optimal order quantity model

EOQ = the economic ordering quantity, or the optimum quantity to be ordered each time an order is placed.

F = fixed costs of placing and receiving an order.

S = annual sales in units

C = carrying cost such as:

- Cost of unavailable capital
- Storage & handling cost
- Insurance
- Property taxes
- Depreciation and obsolescence

$$EOQ = \sqrt{\frac{2(F)(S)}{(C)(P)}}$$

P = purchase price of inventory

7. Optimal Performance

Businesses will achieve optimal performance by minimizing their variable cost and fixed cost through error reduction, process improvement, and customer awareness. Variable costs are the costs associated with completing a process. Variable costs increases as sales increase because of the costs required to complete an order. Fixed costs are the costs required to operate. Fixed costs typically remain constant throughout the year and include: general and administrative, insurance, property taxes, carrying costs of inventory, and other fixed expenses. The relationship between net profit, variable cost, and fixed cost is shown in Figure 16. In order to earn a profit, sales must exceed both variable cost and fixed cost. The point at which both variable and fixed costs are covered is called the *break-even point* (BEP).

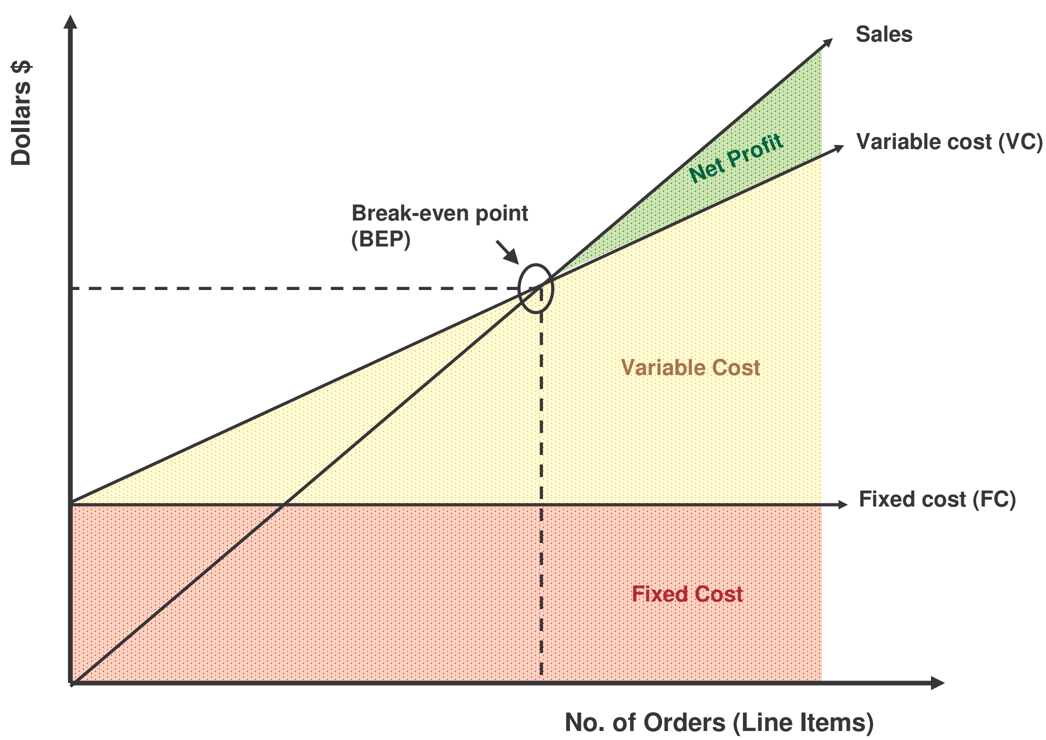


Figure 16. Break-even point of operation

To reduce variable costs (VC), distributors should improve the order fulfillment process. Two ways to improve this process are to:

1. Increase first time pass yield by reducing errors
2. Reduce waste in the process by modifying/removing inefficient steps

In Figure 17, VC_1 is the drop in variable cost as a result of an increase in first time pass yield. VC_2 is the drop in variable cost resulting from both improved first time pass yield and process improvement. Reduction of errors will inevitably lead to process improvement yielding a variable cost reduction expressed by VC_2.

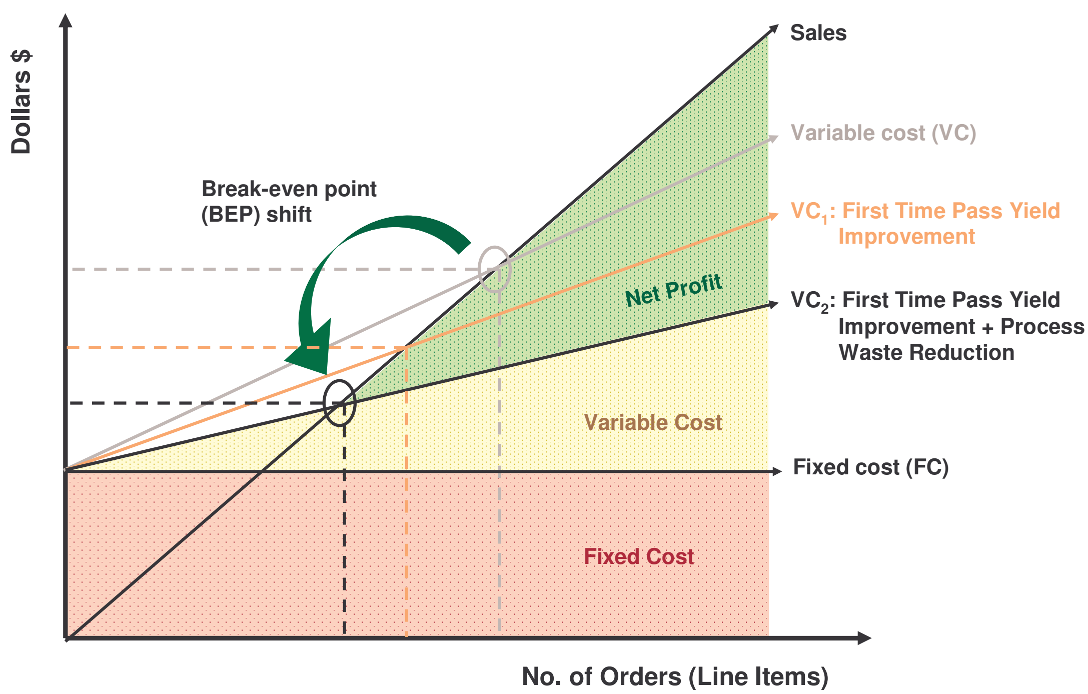


Figure 17. Improvement of BEP by reducing variable cost

Fixed costs can also be a drain on profits. One way to reduce this cost is to adopt new strategies for handling customer's needs. Awareness of the reasons customers make decisions for buying in bulk, ordering same day/next day shipping, or requiring huge inventory present opportunities for improvements. The fixed costs of ordering and carrying inventory can be reduced by advance ordering or ordering only the quantities they need. Figure 18 shows the affects of minimizing fixed costs (FC). FC_2 represents the cost savings when the optimal ordering quantity is reached.

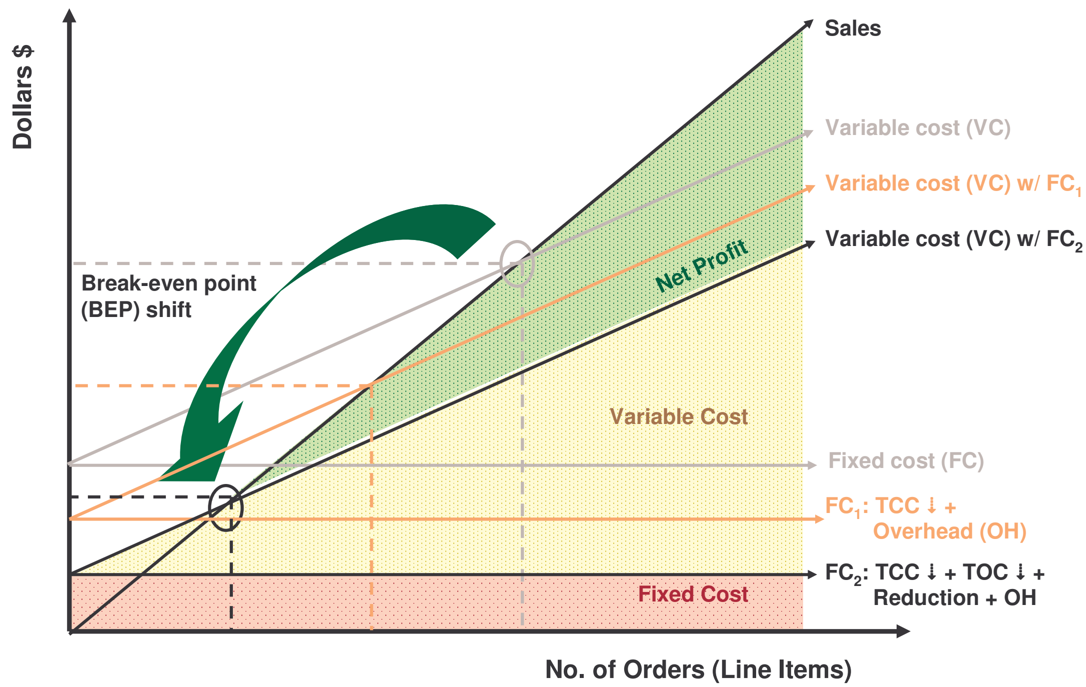


Figure 18. Improvement of BEP by reducing fixed cost

Customer education also prevents rework from buying/returning in bulk and same/next day delivery demands. If the customer is steered away from this mode of operation both variable and fixed costs will be reduced yielding a result shown in Figure 19.

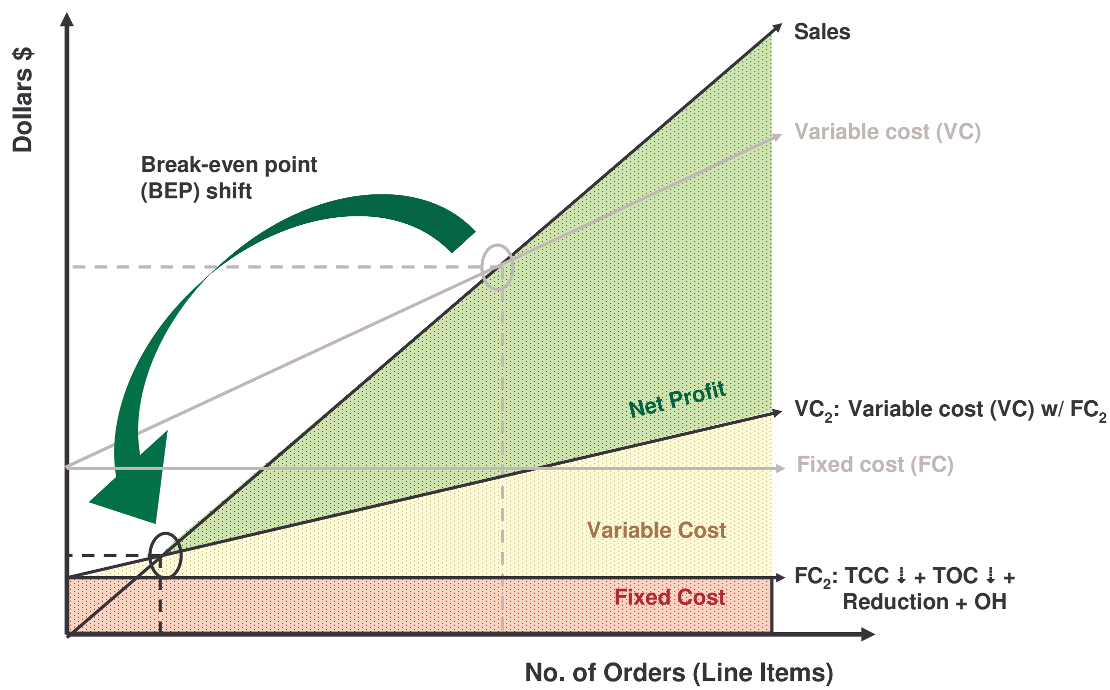


Figure 19. Improving profits by reduction of cost and improved order taking method.

8. Conclusion

Either a business is pursuing a product based service sales or service base product sales operation model, the management needs to identify, verify, and eliminate waste in cost drivers. It doesn't matter if the business is a 5 million dollar operation or 5 billion to increase profits; focus has to be on three major elements of profitability, namely:

1. First time pass yield of order taking and delivery
2. Reduction of waste by making it visible
3. Enter the customer ordering point upstream of their process

If sales are over the counter or bid jobs, in either case following these three focus areas will help improve the system productivity and therefore the profitability.

Changing the operational model to focus on these three factors will equip the distributors with a powerful weapon, which will have the following benefits:

Strategic:

1. Higher customer retention
2. Greater market share
3. Ability to execute strategies
4. Ability to enter new markets

Market:

1. Lower prices
2. Greater customer satisfaction
3. Differentiated offerings
4. Stronger customer relationships
5. Greater agility

Operational:

1. Lower direct cost
2. Better use of assets
3. Faster cycle time
4. Increased accuracy
5. Greater customization or precision
6. More added value
7. Simplified processes

Distributors should start using the well established principles of lean operation. Insanity is to do the same things over and over and expect a different result.

Appendix A. How to Track Rework

A simple form can be used to track rework. The form should include details for measuring the cost and frequency of rework over a given period of time. Some key items to measure would be:

- Each step required to correct the error
- Duration of each step
- Position of person fixing the error at each step (to determine pay rate).

A sample “Rework Tracking Form” is shown in Appendix A. The form has been completed for the picking example shown in Figure 6. Various methods for completing the form are possible and should be incorporated in a way that is suitable for the company. A new form would be generated for each error and the forms could be compiled to watch trends in rework/cost of rework.

Once a Rework Tracking Form is completed the estimated cost associated with each step can be determined with the duration and pay rate of the person involved. Also, the frequency of rework in specific areas can be revealed to show problem areas in the order fulfillment system. Management can use these measures to set goals for the organization and modify the order fulfillment process to improve the system productivity.

Rework Tracking Form

Order #________________________________ Date __________________

Line Item #_____________________________

Step	Step Description	Duration	Job Description	Notes
1	Found error in inspection	5 min	Inspector	
2	Notifed picker who made error	10 min	Inspector	
3	Restocked line item in error	15 min	Picker	
4	Picked correct line item	15 min	Picker	
5	Returned correct line item to inspector	10 min	Picker	
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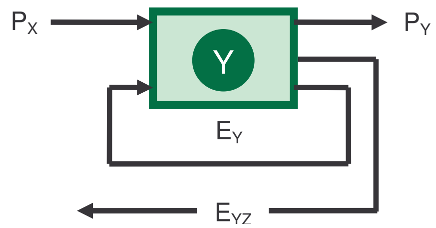
Appendix B. How to Calculate First Time Pass Yield

Complete one form for each step of the process.



1. X = _________ (Previous step of the process)

2. Y = _________ (Step of the process being considered)

3. Z = (All steps prior to Step X)

☐ Step 2	☐ Step 3	☐ Step 4	☐ Step 5	☐ Step 5	☐ Step 6	☐ Step 7
☐ Step 8	☐ Step 9	☐ Step 10	☐ Step 11	☐ Step 12	☐ Step 13	☐ Step 14
☐ Step 15	☐ Step 16	☐ Step 17	☐ Step 18	☐ Step 19	☐ Step 20	☐ Step 21

4. P_X = _________________ (# of line items entering Step Y from Step X)

5. P_Y = _________________ (# of line items produced on first time pass at Step Y)

6. E_Y = _________________ (# of line item errors that occur at Step Y and can be fixed at Step Y)

7. E_{YX} = ________________ (# of line item errors that occur at Step Y and are returned to the previous step.)

8. E_{YZ} = (# of line item errors that occur at Step Y and are returned to previous steps, Z. Use Y from # 2 and all steps from # 3 for Z.)

☐ E__ __ =_____________	☐ E__ __ =_____________	☐ E__ __ =_____________
☐ E__ __ =_____________	☐ E__ __ =_____________	☐ E__ __ =_____________
☐ E__ __ =_____________	☐ E__ __ =_____________	☐ E__ __ =_____________
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Insert values into following equation to calculate first time pass yield of Step Y.

$$P_Y = P_X - E_Y - E_{YX} - E_{YZ} \qquad \text{(For all } E_{YZ}\text{)}$$

Appendix C. Interviewed Companies

Following is a list of companies that were interviewed for this research.

- Advance Electrical
- American & Beacon
- Butler Supply
- Capital Lighting & Supply
- City Electric Supply
- Crescent Electric Supply
- Dakota Supply Group
- Elliott Electric Supply
- Frost Electric
- GE Supply
- Graybar
- Kovalsky & Carr
- Leff Electric
- Mayor Electric Supply
- McNaughton-McKay Electric
- Minnesota Electric
- Quermeack electric
- Sonepar
- Springfield Electric
- Standard Electric
- State Electric Supply
- Steiner Electric
- Summit Electric Supply
- United Electric Supply
- WESCO Distribution

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