News Vendor Problem Simulation of Manufacturing Operations

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Abstract – The classical single-period problems (SPP), or news vendor problem, was applied to the modeling of each station in a five station production assembly line with stations rearranged both in a series and in parallel configurations. Here, production and demand are random variables and a trade-off exists between excess inventory costs due to overproduction and opportunity costs associated with not meeting the needed demand. In this research, the service level of the final product were investigated as a function of the opportunity costs, profit, and the excess inventory costs. The process production performance as a function of process service level was also investigated. The results indicate that higher final product service levels generally lead to lower opportunity costs, lower excess inventory, and higher profit for all configurations. An optimum service level occurs at a performance ratio of μ/σ of 2.0 for two out of three cases.

Keywords: Manufacturing Operations, News Vendor Problems, Service Level

INTRODUCTION

The news-vendor problems, otherwise known also as single-period problems (SPP), are well known classical problems in the business field. The SPP model is based on the behavior of a newsstand where a decision on what quantity to order for a specific day, Q, is made before the demand for the product, D, is known. In this situation, the newsstand buys newspapers for a price, *p*, and sells then at a price of *s*. The unsold newspapers are sold at a discount or salvage price, *c*. When demand is not met, or when Q < D, the newsstand incurs an opportunity loss defined as (D-Q)*(s-p) and earns a profit of Q*(s-p). If the demand is exactly met, or when Q=D, the newsstand expects to incur a profit of (Q)*(s-p). If an excessive quantity amount is ordered or when (Q >D), then the newsstand will sell the excessive newspapers at a discount price, c, to incur an additional profit of (Q-D)*c in addition to the regular profit of D*(s-p).

Many variations of the news-vendor problem have been studied in the literature. Gallego and Moon (1993) applied the news-vendor problem in the fashion and sporting industries, both at the manufacturing and the retail level in these industries. [1] In the application to a manufacturing operation, the goal is usually to find the optimal quantity to produce Q* to maximize the expected profit when demand D is probabilistic and excess production is sold at a discount or completely disregarded. In these cases if production Q is less than the demand D, an opportunity cost is incurred.

Newsvendor problems are considered stochastic models because demand, D, and production, Q, are usually probabilistic values. These variables are probabilistic in that they can be impacted by many external and internal factors. Tang and Tomlin (2008) research mentioned situations where these variables can be impacted by disruptions of the supply of products, disruptions within a process and the demand risks associated with demand uncertainty that could be as a result of political, economical and social turmoils.[2] Newsvendor problems have been mostly analyzed as a single station problems where the following parameters Q, D, c, s, p have been constrained in a specific form or are considered to be random variables that follow a specific probability distribution. Moutaz K. (1999) performed a literature review where it showed that the SSP problems have been adjusted for different objective functions, different pricing policies and discounting policies for both Q and D, and different modes of handling excess inventory.[3] The different objectives have ranged from maximizing profit, to maximizing a specific target profit, to maximizing return on investment and to maximizing other utility functions. [4], [5], [6] The pricing policies set by a producer of Q have varied from being dependent on the expected demand D in some mathematical manner to being fixed variables. [7] The pricing policies for selling excess inventory have also varied. Khouja (1995) incorporated multiple discounts for selling excess inventory in the analysis of SPP. [8]

Newsvendor problems have been extended to multi-stations and multiproduct situations. Van Mieghem, J. A., and Rudi, N., (2002) in extended the SPP problem to these situations, termed the analysis of such problems as Newsvendor Networks.[9] In this particular research, the excess inventory left from one period was carried over as input to the next period. In this particular research, the amount that could be produced, Q, is constrained by the capacity of the manufacturing operations as well as by the safety level required for the inventory of supplies need for production of multiple products in two different processes. By operating in this manner, the analysis of the proposed model covered additional inventory holding costs in the objective of maximizing operating profit. Baker et al., (1986) analyzed a two product inventory model that used common components to build two different products. [10] The goal here was to minimize the total inventory of all components or safety stocks of all components while satisfying service level requirements triggered by the demands D_1 and D_2 of each product. This research is relevant to certain aspects of an SPP problem which include the inventory of supplies to produce Q units of production and the excess inventory due to overproduction or when Q> D.

In this research, we are extending previous SPP research to include the investigation of how service levels and expected profits are related for SPP multi-station processes. The focus of this research is on maximizing the final product service level-an indicator of customer satisfaction. Achieving customer satisfaction is sometimes considered more important than profit because there are tangible and un-tangible costs associated with not achieving full customer satisfaction. According to Anaya, et. al (2011), a "dissatisfied customer has many options to pursue: 1) he/she may simply terminate the transaction relationship, 2) voice his/her frustration through negative Word of Mouth (WOM), and even 3) seek legal restitution as compensation." [11] These measures taken by an unsatisfied customer can lead to higher profit losses than the ones that could be accounted for by standard accounting practices. With the addition of the Internet, there are now more options available to a dissatisfied customer that can easily cut into the profit of any corporation. Since most of the research related to SPP problems have been done to two stage process situations, the contribution of this research is that SPP research is being extended to assembly line operations that extend beyond two stations and rearranged in different configurations.

DESIGN EXPERIMENT

Using graphical object-oriented programming software, Labview, three different five station assembly operations rearranged in the following specific configurations were simulated, with each station being an SPP station. The following figures illustrate the three cases tested in this experiment:

Figure 1: In-series Process

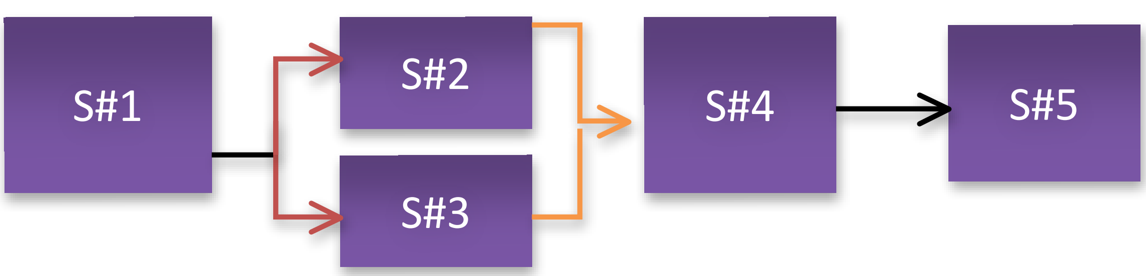

Figure 2: Parallel System 1

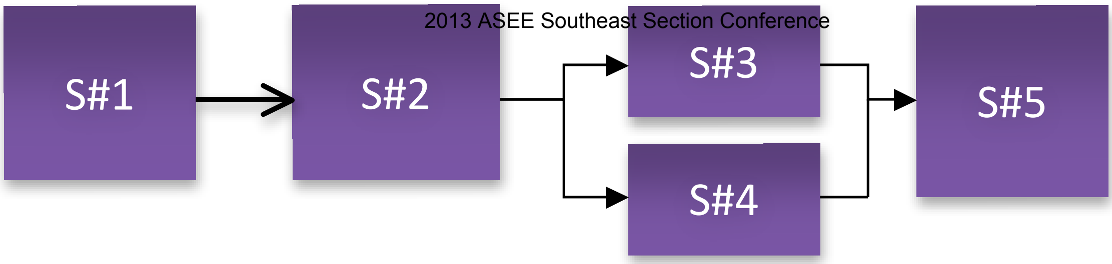

Figure 3: Parallel System 2

For each process, the SPP model was applied to each station with the demand for the final product being triggered by a customer at the end of station 5. The production for each specific station was triggered by the demand of the upstream station. For each process, the simulation was run for 8 hours a day, for a period of one week. In the series process, the production for station 2, P_2 is set to be equivalent to the demand for station one, or $P_2=D_1$ and similar constraints exist for the subsequent stations in the process. In the parallel process, similar constraints exist for the stations in series, but for the parallel stations the constraints are modified to reflect the distribution of the production of two parallel stations being equivalent to the demand for the preceding station. As an illustration for parallel system 1, $D1=P_2 + P_3$ where $P_2=XD_1$ and $P_3= (1-X)D_1$ where $0 \leq X \leq 1$. In this simulation, the percentage distribution X were tested at X=0 to X=1.0 in increments of 0.25 for a period of 5 days, with each day having a different X value. Excess inventory in any station was neglected or presumed to be discarded.

The costs associated with each station are listed in the following table. These values were selected randomly and used only to make a comparison between processes in determining profit and the opportunity costs associated with each process.

Table 1. Baseline Processes Value Parameters

Station	Production unit cost, *p*	Selling unit price, *s*	Salvage unit price, *c*
1	0.45	0.60	0.08
2	0.60	0.70	0.10
3	0.70	0.90	0.15
4	0.80	1.00	0.20
5	1.00	1.50	0.25

RESULTS

Service Level Analysis

In this research, opportunity cost, process profit and excess inventory were investigated as a function of the final product service level provided to the customer requesting the final product from the assembly operation. The results vary for each type of process simulated. For the in-series process, the opportunity costs vary linearly as a function of the final product service level in the following manner

Total Opportunity Cost = -56.93*Service Level + 81.433 with an $R^2 = 0.602$.

This indicates that to minimize the opportunity cost, the service level has to be increased as expected. Keeping the customer satisfied by meeting the demand for the product minimizes the opportunities to loose potential profit (i.e. opportunity cost).

For the parallel system #1, the results indicate the following relationship for opportunity costs:

Total Opportunity Cost = -3493.5*(Service Level)^3 + 4227.1*(Service Level)^2 – 1474.6*(Service Level) + 189 $R^2 = 0.99$

The actual data indicates that the highest opportunity cost occurs when the production from station1 is equally distributed to station 2 and station 3. At this point, the final product service level was found at the minimum.

For parallel system #2, the results indicate the following relationship for opportunity costs:

Total Opportunity Cost = -423.93*Service Level + 263.32 with an $R^2 = 0.998$

As in the previous processes, to minimize the total opportunity cost, the final product service level has to be increased. When it comes to minimizing the total opportunity costs, the final product service level has to be increased for all three processes. Figure 4 illustrates that increasing the final product service level for parallel system #2 has a bigger effect on minimizing the total opportunity cost for this process than for the other two processes as the total opportunity cost has been minimized to zero for a final product service level of 0.6.

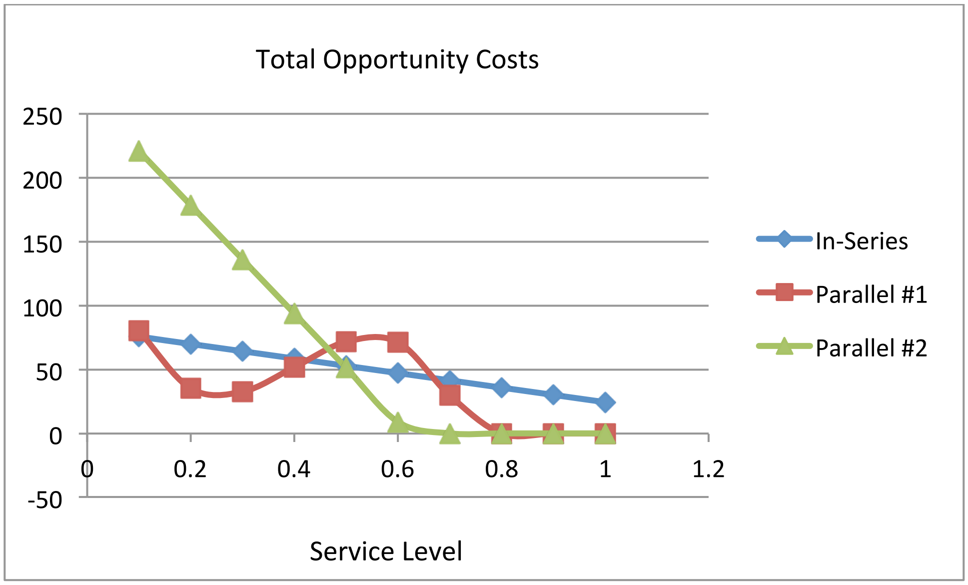

Figure 4: Total Process Opportunity Costs

Regarding the behavior of process profit in terms of service level, the data indicates that the processes behave differently. For the in-series process, the process profit also varies linearly as a function of the final product service level as follows:

Total Process Profit = 52.1999*Service Level + 101.73 $R^2 = 0.7787$.

The results indicate that the higher the level of customer satisfaction (as denoted by the higher the service level provided), the higher would be the expected profit for this process.

For parallel system 1, the relationship between the total process profit and final product service level was best determined by a polynomial relationship and is given below:

Total Process Profit = 1936.6(Service Level)^3 – 2237.7*(Service Level)^2 + 769.42*(Service Level) + 53.323

$R^2 = 0.99$

The results indicate that the minimum process profit occurred at a service level of 0.125, which corresponds to the situation where the production from station 1 was equally distributed to station 2 and station 3. The highest process profit occurred when ¼ of the production from station 1 when to station 2 and ¾ of this production went to station 3.

For parallel system 2, the relationship between total process profit and the final product service level is given by the following equation.

Total Process Profit = 130.08*(Service Level) +43.382 $R^2 = 0.998$.

This indicates that to maximize profit, the service level has to be increased. The results also indicate that to maximize profit, the production from station 2 have to be equally distributed to station 3 and station 4 or X= 0.5. The actual data revealed that the highest process profit level was achieved at a final product service level of 0.5.

In summary, final product service level impacts the process profit in different ways. Figure 5 illustrates how profit varies as a function of final product service for all three processes. For all three processes, the highest profit occurs at the highest service level. Achieving 100% customer satisfaction in meeting the demand of the product yields the highest profit regardless of the process configuration.

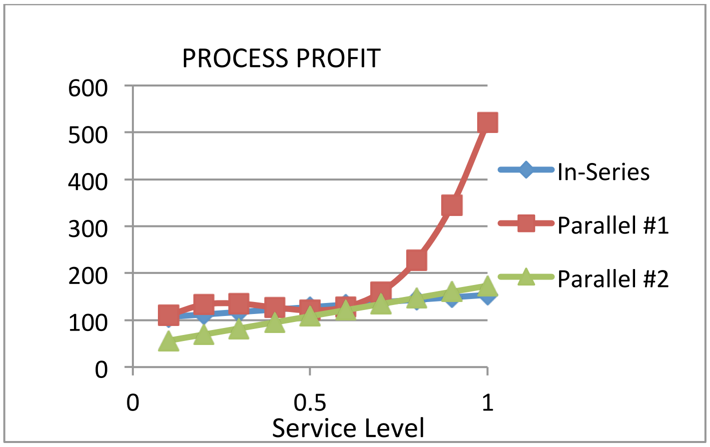

Figure 5: Total Process Profit

Regarding the behavior of the excess inventory as a function of the final product service level for the three processes, the results indicate that different relationships exist. For the in-series process, the excess inventory as a function of service level is given by:

Total Excess Inventory = -174.98*Service Level + 310.54 with $R^2 = 0.4975$.

The results indicate that as the service level increased, the level of excess inventory diminishes. These results were extended to find profit as a function of excess inventory which resulted in the following relationship:

Total Profit=-0.1542*Excess Inventory + 160.66, $R^2 = 0.4184$. I

This indicates that the more excess inventory exists, the less process profit will be achieved. To maximize profit, excess inventory which is determined as P-D while P>D needs to decrease. From these equations, the conclusion is that for an in-series SPP process, maximizing final product service level leads to maximizing profit while at the same time minimizing excess inventory. Minimizing excess inventory for a fixed demand, D is possible as long as the constraint P > D is satisfied.

For the parallel system 1, the following relationship between the final product service level and the excess inventory was found.

Total Excess Inventory=-97.01*(Service Level) + 229.9 $R^2 = 0.49$

Total Process Profit = -0.0094*(Total Excess Inventory)^2 + 5.147*(Total Excess Inventory) - 572.84 $R^2 = 0.971$

For the parallel system 2, the relationship between final product service level and total excess inventory is given by the following equation:

Total Excess Inventory = -123.32*Service Level + 202.14 with $R^2 = 0.838$.

The results indicate that to minimize total excess inventory, service level has to be increased.

Total Process Profit = -0.4168*Excess Inventory + 156.15 with $R^2 = 0.499$.

Figure 6 illustrates how the total process excess inventory varies as a function of final product service level for all three processes. The figure illustrates that the in-series system generally will have more excess inventory than the parallel systems.

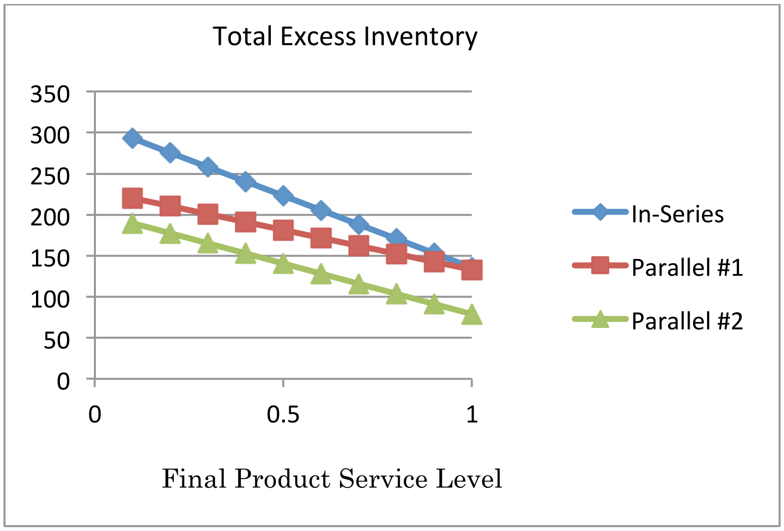

Figure 6: Total Process Excess Inventory

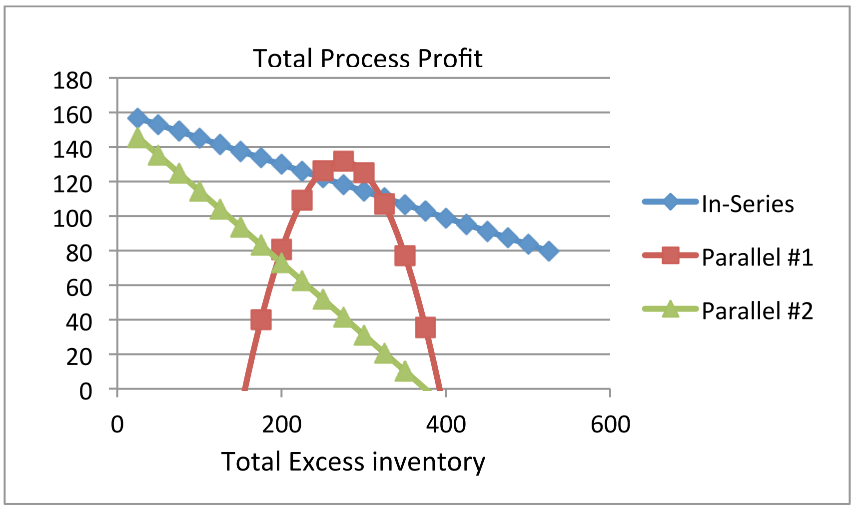

Figure 7: Process and Total Excess Inventory

Figure 7 illustrates that total process profit decreases as total excess inventory increases for the in-series process and for the parallel system #2. But for parallel system 1, there is an optimal excess inventory level needed to maximize process profit.

Process Performance

Process performance can be measured by the signal/noise=μ/σ ratio of a production process. [12] In this research, the μ/σ ratio was applied to the production produced by the station and then averaged for the entire process. The service level performance was obtained for each station and then the average of these service levels performances was used as the service level performance for the entire process.

The results indicate that for the in-series process, process performance is related to the average process service level as follows:

Average Process Service Level=-0.4298*(process performance)^2 + 1.7775*(process performance) – 1.2406 with R^2 = 0.879

This indicates that an optimal average process service level occurs at a specific level of process performance. The data reveals that optimum service level of .575 occurred at μ/σ ratios >1.76.

The results indicate that for the parallel system case 1, the average process service level is related to the production performance as follows.

Average Process Service Level = -0.1851*(process performance)^2 + 0.7882*(process performance) - 0.3373 R^2 = 0.533

The data reveals that the optimum service level occurred at a service level of average process ratio of μ/σ ratio of 1.80.

The results indicate that for the parallel system case 2, the average process service level is related to the production performance as follows:

Average Process Service level= 0.0588*process performance + 0.2915. $R^2 = 0.6167$

This indicates that the higher the performance of the process is, the higher the average process service level. For this specific process, the actual data revealed that the highest service level occurred at a μ/σ ratio of 1.85. Figure 8 illustrates the behavior of these relationships for all three processes. Two of the processes indicate that a maximum service level performance occurs at a μ/σ ratio of about 2.0. For the parallel system #2, the higher the process performance, the higher the average service level provided by the process.

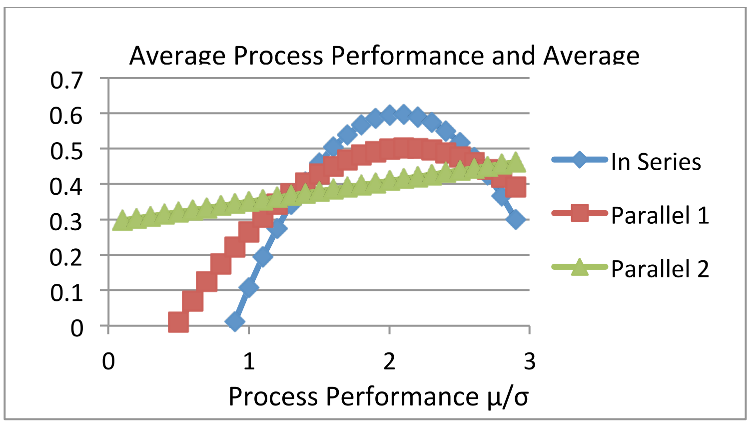

Figure 8: Average Process Service Level and Process performance.

DISCUSSION

The results indicate that the SPP model can result in expected results for an assembly line operation that extends beyond two stations and also for assembly line operations that have different configurations. For all three different processes considered, the higher the final product service provided, the lower the total opportunity cost, the higher the expected profit for a process, and the lower the total excess inventory generated in the process. Not all the relationships between the variables considered were linear. This was particularly true for parallel system 1 when it involved determining opportunity cost, total process profit, and excess inventory as a function of final product service level. For parallel system 1, an optimum profit results at a specific level of excess inventory.

Regarding process performance, the results indicate that for the parallel system #2, as the process improves its production process performance, the greater the average level of service being provided. This indicates that as each station improves its production process in terms of improving the signal/noise =μ/σ ratio, the greater the service level being provided to the upstream station. For the other two systems, an optimum service level occurs at a μ/σ ratio of about 2.0.

FUTURE RESEARCH DIRECTION

The results of this simulation can be extended to include more than five stations and other possible configurations. The results can also be extended to consider the effect of using leftover inventory for the upstream station. In this particular simulation, excess inventory from one station was not considered for the next upstream station. Regarding inventory, the results can also be extended by establishing certain policies for inventory of the final product, for the work-in-process (WIP) product inventory and for the incoming supplies. These policies could include a minimum safety stock being established for each type of inventory, the consideration of a fraction of damaged inventory, etc. The results can also be extended to include different pricing policies in selling the final product (e.g., discounts could be extended to customers buying product in bulk). Lastly, the results could be extended to maximizing or minimizing other objective functions (e.g., minimize excess inventory, maximize return on investment, etc.) that are considered important in ensuring that the demand for a product will be met by the process.

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