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Spreadsheet Simulation for Understanding Manufacturing Flexibility

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Spreadsheet Simulation for Understanding Manufacturing Flexibility

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Keywords
Proecss Flexibility, Manufacturing, Simulation, Operations Management

Spreadsheet Simulation for Understanding Manufacturing Flexibility

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1. Introduction

The job of any operations manager is to fulfill the customers' demand. While, demands can fluctuate, the production capacities are more or less fixed. Therefore, managers always seek to make their operations flexible. In a flexible operation, productions can be adjusted to the changes in demands without "undue increase in cost or time to delivery" [11].

For example, if a company produces five different models of a certain product (say garment), each of them has a demand of 100 (on average) matched by a fixed production capacity. Here, because the production capacities are fixed, sales will be lost for the models whose demands were above average. At the same time, some other production facilities can remain underutilized. So, even if the demand on average was 500, which is equal to total production capacity, losses in sales and production often occur at the same time. On the other hand, flexibility allows production to shift to the items with higher demand, thus improving in plant utilization as well as the customer service.

Flexibility is often described in terms of flexible manufacturing systems (FMS). These hi-tech systems have potential to change from one product to the next in a short notice. However, given their high costs and complexities during installation and operations, using FMS to achieve a complete flexibility is impractical in many circumstances [10].

In this context, Jordan and Graves (1995) showed that partial flexibility (where plants can make one other model, besides its primary one) can be deployed. It achieves most of the benefit of the flexibility, at much lower cost compared to the full flexibility. Even though, Jordan and Graves (1995) paper was written in the context of simulation they conducted for GM, their outcomes have applications in other

situations as well. They are referred to and elaborated in many text books [1, p 344-349; 8, Chapter 7).

In this paper, we present two sets of simulations exercises (Flexibility Experiment.xlsm and Flexibility Experiment11.xlsm.) Both are available for downloading along with this paper. These exercises allow students (or others interested in it) to experiment on how various stages of process flexibility along with different values of mean demands, variation in demands, plant capacity and number of plants (models) impact the customer order fulfillment percentages and capacity utilization percentages. In the first model, one can experiment by changing values of any of the four factors- i.e. mean demands, variation in demands, plant capacity and number of plants. In the second model, which is an extension of the first, each one of these factors change their values in increasing order, while other three remain same, and the impact of the change in the customer order fulfillment and the plant utilization is demonstrated. In both models, the degrees of flexibilities change. As we describe and present our simulations models, we also elaborate on the outcomes, and discuss their implications in various manufacturing decision making situations.

2. Concept

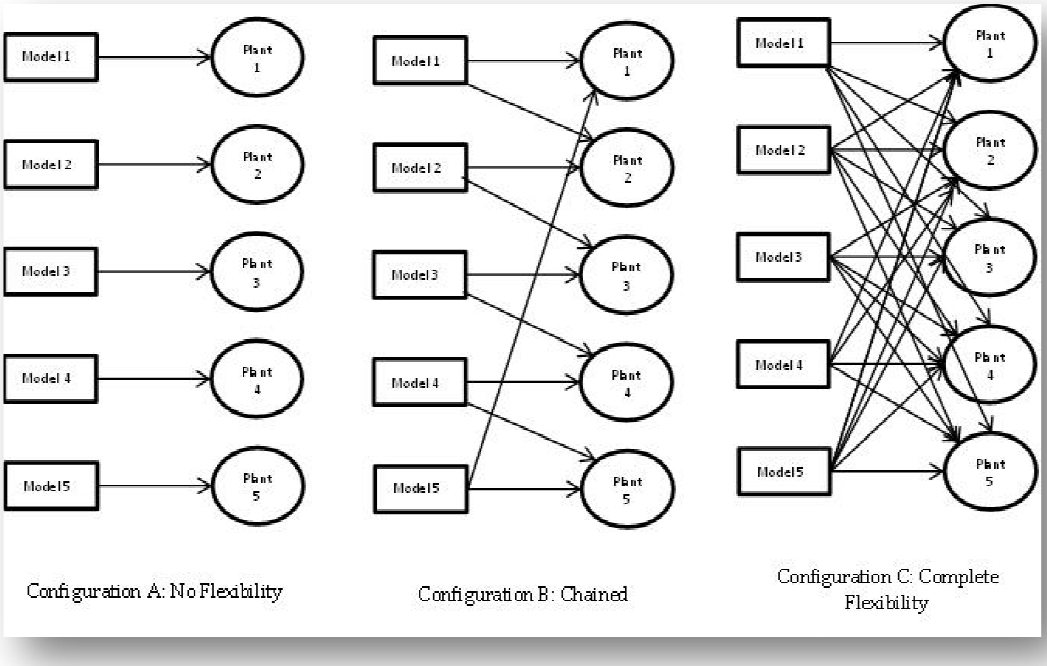

Figure 1: Different Stages of Flexibilities

The outline of this section is drawn from the seminal article from Jordan and Graves (1995). The main problem here is while the capacity of the each plant is fixed, demand can only be forecasted. And, such forecasts have inaccuracies (uncertainties), which are represented by standard deviations. Mean demands are the forecasted demands. Moreover, while aggregate demands can be forecasted fairly accurately, because inaccuracies in individual forecasts cancel out each other, inaccuracy increases when forecast is attempted for separate individual demands of

each model. So, even if the business can forecast the aggregate demands for the garments (for example), their forecasts for the individual models are less reliable.

The process flexibility discussed here is exhibited in the figure 1. As per the figure, there are five plants of a (garment) manufacturer. Each plant is primarily responsible for producing one model. In configuration A, each plant produces one models only, there is no flexibility. In a fixed capacity and fluctuating demand situation there can be loss of sales and underutilization of the capacity as the same time. Configuration B is called chained. Here Plant 1 is primarily responsible for producing model 1, but it can also produce model 5, if it has spare capacity and the demand for model 5 is higher than what plant 5 can produce. Similarly, plant 2 is linked to plant 1 and so on. Thus, every model can be produced by one more plant besides the one primarily responsible for producing the same. This called chained model. The final one, configuration C, each plant can produce every possible model. This is a complete flexibility. Increase in flexibility reduces the mismatch created by uncertain demand and fixed capacity.

In this article, we conduct experiments aimed at helping students/ decision makers to appreciate on the extent of "process flexibility" required to adequately and efficiently meet the ever uncertain demand.

3. Simulation

This study uses Monte Carlo simulation to conduct experiment allowing readers to appreciate the concept of process flexibility. Monte Carlo simulations generate random numbers pertaining to different scenarios [6, p 582-587]. Here, one random number is generated to represent a demand for each model (of the garment, for example.)Thus in each scenario, as many random numbers are generated as the numbers of models, because demands for one model is independent of the other. The random number thus generated depends on the mean and standard deviation provided by the experimenter. We have assumed the demand to be normally distributed. However, to avoid extreme and negative values the lowest demand value can be 20% and the highest can only be 180% of the mean. This follows the overall framework of Jordan and Graves (1995) original simulation [1, p 344-349; 4].

Simulation is used when analytical solution for a problem is very difficult, if not impossible. This case, with a process encompassing multiple plants with different demands and capacity, is one such problem. Further, simulation creates history for the process, by running multiple scenarios with different possible inputs (i.e. random numbers), giving the experimenter adequate descriptions of the possible outcomes [6, p 582-587].

Macros generated by VBA codes are utilized to generate random numbers. The codes generate the numbers multiple times automatically creating multiple scenarios. They are also used to calculate average percentages of plant utilizations and demand fulfillments in order to provide data for the graphs. These graphs contain results of the experiments. Excel spreadsheet is used here to provide inputs by the experimenters and also for outputs in graphical forms after running the experiment.

Our model identifies four other important factors, which impact (average) percentages of plant utilization and demand fulfillment. These factors are average demand, standard deviation of demand, plant capacity and number of plants. In our simulation, experimenter can vary average demand and plant capacity each from 50 to 500. There is a standard deviation for demand which can vary from 5 to 75, showing that demands are random around mean while capacities are fixed. And, number of plants can vary from 5 to 25. In this simulation researcher can change each of these values using scroll bars (as shown in figure 2). The final result of the experiment is shown (in graphical form) after hitting the run button.

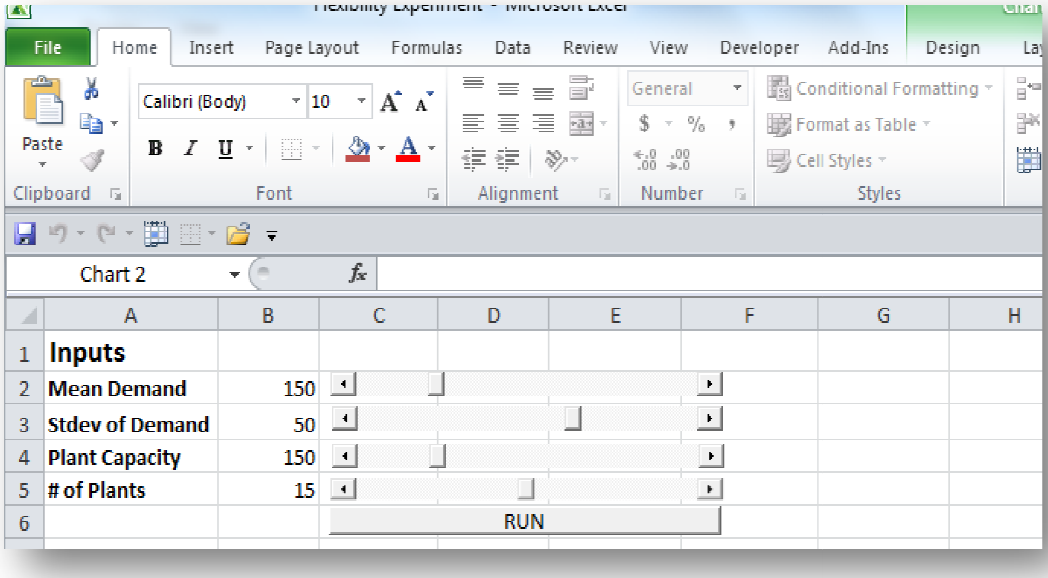

Figure 2: Input for Simulation

Besides, every simulation should have model that is adequate enough to represent the problem. Still, it should also simple enough [6, p 582-587]. Following the spirit, we allowed each of the plant to make one model only. In case there is a plant that makes two models, for example, in two different assembly lines, we can consider this as two plants for our purpose. And, if two plants make same model, they can be considered one. Moreover, the purpose of our experiment to see whether each plant should make one model or more, one model per plant as a beginning assumption is adequate.

Still, our models do not incorporate operating cost including such as setup (extra cost for changing assembly line from one model to another) and, transportation (extra cost for transporting components of model 1 to plant 5 instead of regular plant 1 and for transporting model 1to the market from plant 5 instead of plant 1, for example). This issue, though very important, can be addressed after the strategic decisions once the extents of process flexibilities of the plants are decided. And, there are various optimization tools (such as transportation programming), which can be used to decide on the assignment issues as to what (how much) is to be made where and at what costs [6, p 214-231]. Our model is adequate to verify the importance of process flexibility and understand various aspects of it.

After the inputs for the four factors are provided, the extents of demand fulfillment and capacity utilization depend on the level of the flexibility of the process (denoted by the number of links in figure 1). In the Configuration A, even when the total demand is equal to (or even less than) the total plant capacity, there can will be underutilized capacity and also unfulfilled customers' demands at the same time. The randomness can create below average demand and the particular plant can be underutilized. Similarly, it can also create above average demand leading to unfulfilled capacity for the next plant.

In the chained link (Configuration B) demand can be transferred. If demand of model 5 is greater than the capacity of plant 5, and if it (model 5) is also linked to plant 1 via a chain, then unfulfilled demand (demand 5- plant 5 capacity) can be transferred to plant 1, provided plant 1 has that much extra capacity. The extra capacity in plant 1, on the other hand, depend on demand of model 1, plant 1 capacity and how much can be transferred to plant 2. In this case, if the link continues demand from plant 5 can be transferred all the way to plant 4. However, if demand of model 5 is lower than the capacity of plant 5, then the underutilized capacity is lost, and that much of the demand remains unfulfilled.

Further, this study allows experimenter to set the number of plants (i.e. number of models). For example, if fifteen models are chosen instead of five then plant 15 is connected to plant 1, and everything else follows the explanations given above.

When, there is complete flexibility (Configuration C), any unfulfilled demand can be transferred to any plant with extra capacity. However, due to randomness in demand, if the total demand is less than total capacity, the capacity remains underutilized. On the other hand, if the total demand is more than the total capacity, the demand can go unfulfilled.

This simulation is available in the file "flexible experiments.xlsm." The results discussed below are based on the experiments we conducted using this file. The reader can choose from wide ranges of values in different combinations than what we have done here and reach his/ her own conclusion.

3.1. Results and Their Implications

Figure 3 shows the outcome of the experiment with the inputs shown in figure 2. The graph shows the impacts of increase in flexibility on demand fulfilled and capacity utilization percentages. Percentage of demand fulfilled is calculated as the percentage of actual production as compared to the market demand. Similarly, percentage of capacity utilization is the percentage of actual production as compared to the total capacity.

As can be seen (from figure 3), the result shows that with the increase in flexibility, the capacity utilization increases and so does the demand fulfillment. In our particular case, without flexibility the capacity utilization (and demand fulfillment) is around 86% (and 87% respectively). This figure increases to around 94% (and 96% respectively), when there is complete chain link (i.e. fifteen extra links compared to the base case of without flexibility). And for full flexibility these figures increase to around 97% (and 97% respectively). Thus the increase in flexibility allows business to

take benefit of increasing capacity, without investing in new machines and facilities. This happens, because loss from the mismatch between the demand and supply is dramatically reduced in a flexible process. And, flexible lines are more balanced; workers and machines each of the workstations will be working (more or less) equally in a given day [1, p 344-349; 4].

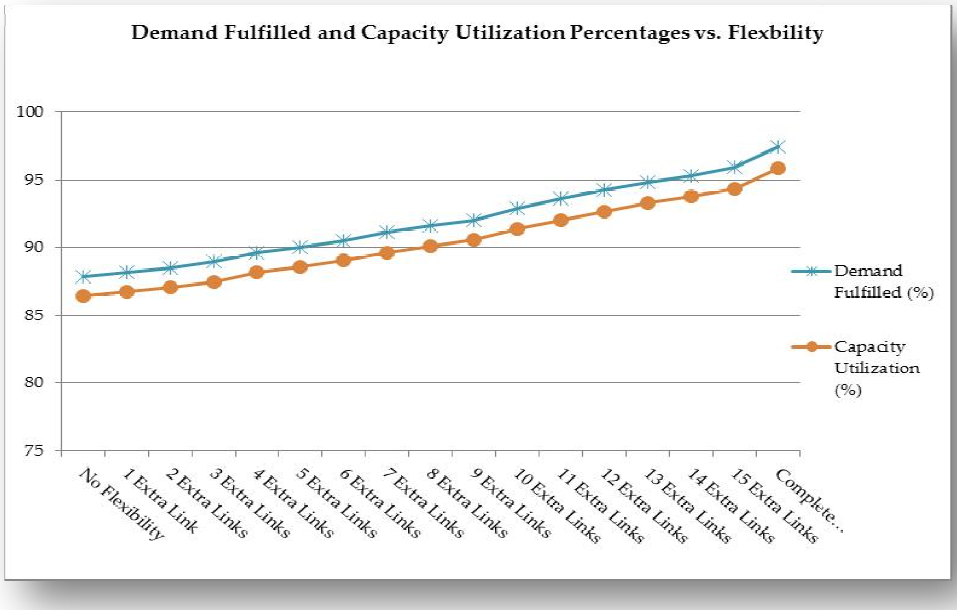

Figure 3: Outcomes of the simulation

Since, there is randomness in demand; it is possible to have of extreme results in any one run. Therefore this program runs fifty times, and values capacity utilization and demand fulfillment percentages discussed above, are the average of these fifty runs. A sample of the size of fifty, where inputs (i.e. demand values) are drawn from normal distribution as well, can be considered to be normally distributed. So, the mean values of capacity utilization and demand fulfillment percentages are used to represent the average here. It means results discussed here are representative of what happens in the long run. Still, in any single run (or any single season in real life) the results could be quite different from what is expected. This is a risk every decision maker has to understand.

Further, there are other issues to consider as well. A nonflexible system requires dedicated machines and workforces, and can be less costly to install and run. Flexible system, on the other hand, can be costly. To achieve flexibility, first the production machines should be flexible. This means they should be able to be reconfigured, and setup for the new productions quickly and easily, without much loss in time and money. And, workers should be trained to do be able to switch jobs easily efficiently to have meaningful flexibility. To have a complete chain each plant should be able to produce two items (or two models of garments for example), with almost equal dexterity. Again, moving from chains to complete flexibility can increase the cost many times [1, p 344-349, 4]. For example, in our case complete flexibility means the machines should be able to be reconfigured in fifteen different ways, and people should be proficient in fifteen different jobs.

Businesses exist to make money, increases in capacity utilizations can be justified to the extent they help businesses to add values. If the demands are low, improving capacity utilization by increasing flexibility does not add any value. When demand and supply are close (as in our case), increases in capacity utilization and demand fulfillment percentage by making a complete chain (by requiring each plant to be proficient in production of two different models), can be economically justifiable [1, p 344-349, 4]. In our case the average demand and capacity are both same (150) and therefore demand fulfillment and capacity utilization percentages increased by more than 9% each, with increase in flexibility. However, most of the improvements are achieved when process changes from no flexibility to the complete chain. However, a completely flexible system is a different story. Learning fifteen skills and configuring machines in fifteen different ways can be prohibitively costly. And increase in capacity utilization from a chain (with fifteen extra links in our example), where each station has to be able to do two jobs properly, to complete flexibility (which requires a two hundred and twenty five extra links) is about 1%. This improvement would not be sufficient to justify cost and complications in most cases.

Toyota have worked tirelessly to reduce the setup time in their stamping machines in order to be able to produce many different models, without much loss of time and money. They also teach workers skills pertaining to their own station, and those on their either sides, making them flexible. Thus, they aim for the system that is flexible enough and practically possible and economically viable. They do not target for complete flexibility [1, p 179-218 & 344-349; 2, p 59; 8, Chapter 7]. Our discussions above show the viability of such approaches.

4. Extension

The model presented here, investigates the impacts of by four factors, which are mean demand, standard deviation of demand, plant capacity and number of plants, on plant utilization and demand fulfillment percentages. The extension (Flexibility_11.xlsm) intends to find the impacts of changes of values of one of those four factors on plant utilization and demand fulfillment, while keeping other three constant. Beside these adjustments most of the things discussed in section 3 is valid here as well.

Figure 4 shows input for the extension. The constant default values for average demand, standard deviation of demand, plant capacity and number of plants, are 150, 50, 150 and 15 respectively. There are four radio buttons, one each for average demand, standard deviation of demand, plant capacity and number of plants. Whichever is chosen, the value of that factor changes and other remains constant. For example if average demand is chosen, its value starts from 50 and changes to 100, 150, 200 and 250 in each cycle while other values remain constant in their default positions. When run is pressed, then the program runs five times (each time with different demand) and creates graphs like those shown in figures 6 to 12. The details of which are discussed in the following passages.

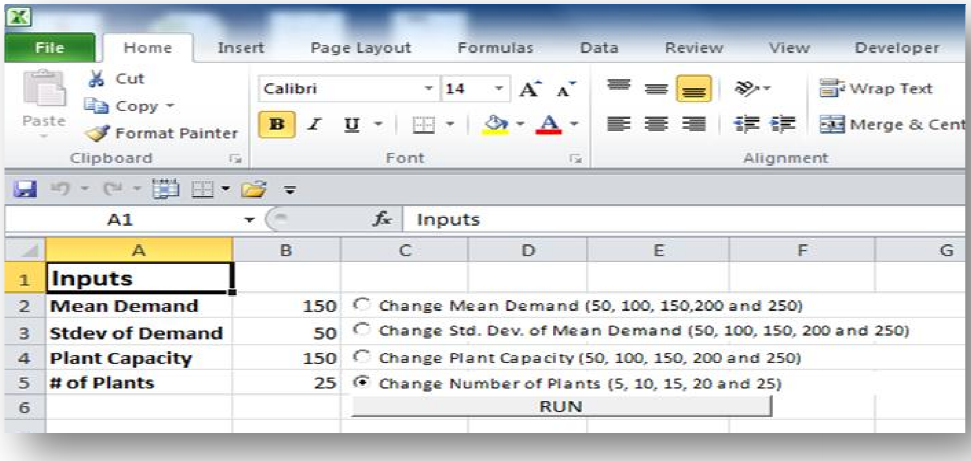

Figure 4: Inputs for Extension

4.1. Findings of Extension

This part discusses the finding and the implications, from the four experiments carried out in the extension simulation.

4.1.1. Changing the Average Demand

First experiment in extension is done by choosing average demand value to change. It changes from 50, to 100, 150, 200 and 250, while other factors remain at their default values. The plant capacity remains 150. The results of this run are shown in figures 5 and 6. Figure 5 shows the impact of changes in values of mean demand on the demand fulfillment percentages, and figure 6 shows the impact on capacity utilization percentages.

These two figures show that the flexibility created by links have value (as discussed is section 3), only when mean demand and plant capacity for each of the plants are equal. When demand is too high or too low, adding links do not have any impact on demand fulfillment or plant utilization. For example when demand is 250 (on average) and plant capacity 150, demand fulfillment is low (just above 60%) and plant utilization is almost 100%, with or without links. Similarly, when demand is too low, the demand fulfillment is high and plant utilization is low.

There is another important insight as well. When demand is lower than the capacity, for example mean demand of 100 against the plant capacity of 150 in our case, the demand fulfillment rate is high but utilization percentage is low. As stated above, the goal of operations is not to increase utilization per se, but to add value by serving customers. Having extra capacity requires higher investment as well as higher operating cost. And, adding extra links for increase in demand fulfillment rate, and as discussed above, also requires higher investment and operating costs. So, extra capacity is another type of flexibility [1, p 171-172]. Managers have to decide on whether they want extra capacity, flexibility by increasing links or combination based on cost-benefit analysis for their particular situation.

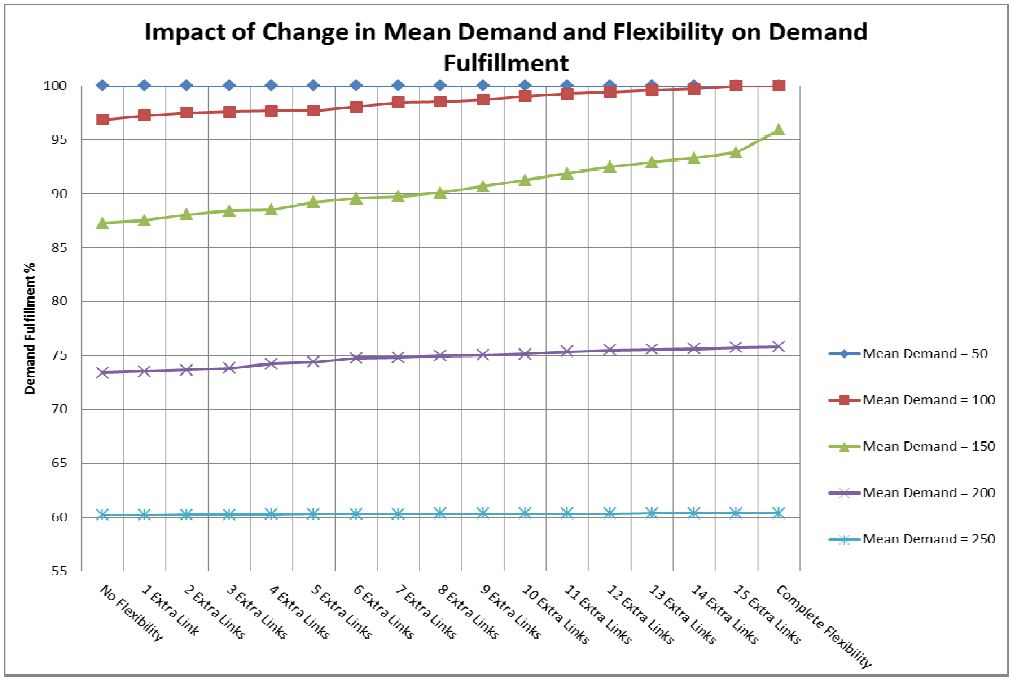

Figure 5: Impact of Change in Mean Demand and Flexibility on Demand Fulfillment

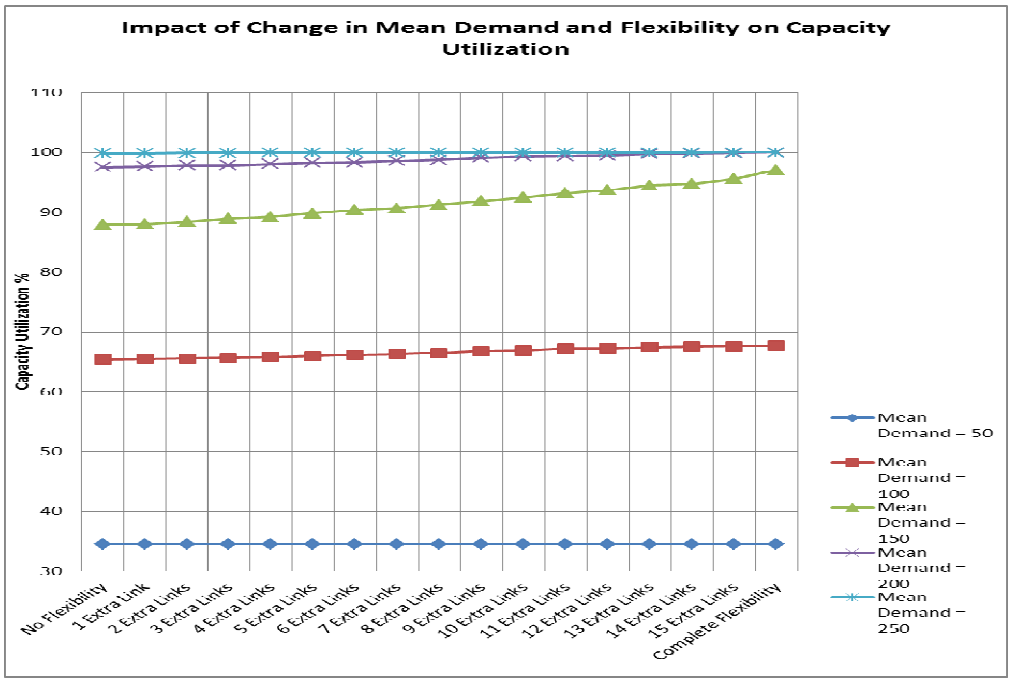

Figure 6: Impact of Change in Mean Demand and Flexibility on Capacity Utilization

Since changing demand while keeping capacity constant is equivalent to changing capacity while keeping demand constant. The results of this experiments are similar to the one discussed here, and can be interpreted in the similar fashion. They are shown in figures 7 and 8. And, no further discussion is done for this section.

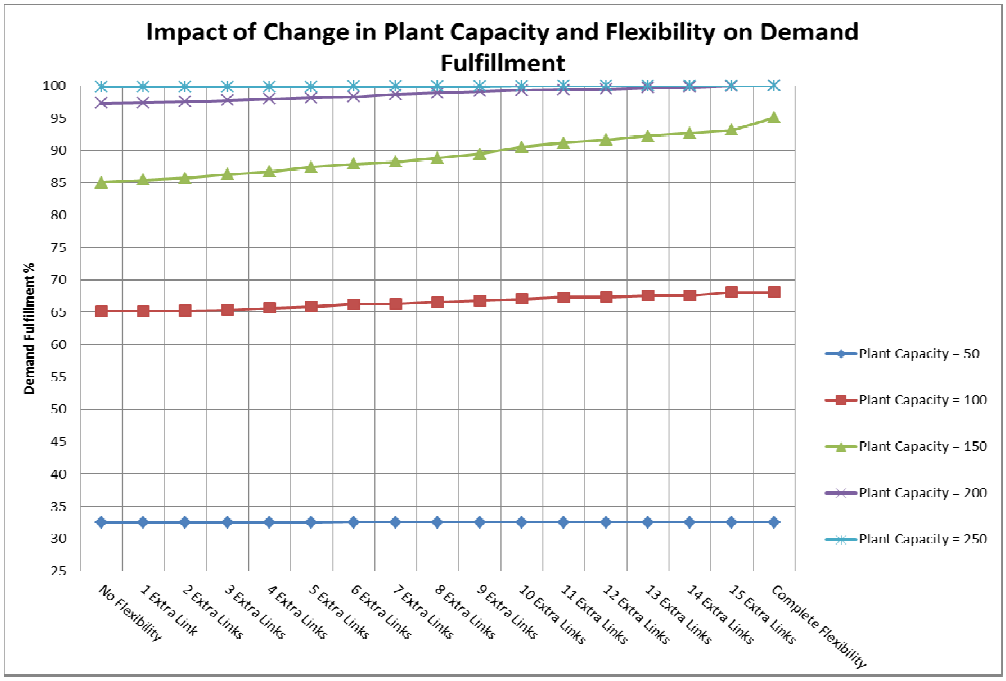

Figure 7: Impact of Change in Plant Capacity and Flexibility on Demand Fulfillment

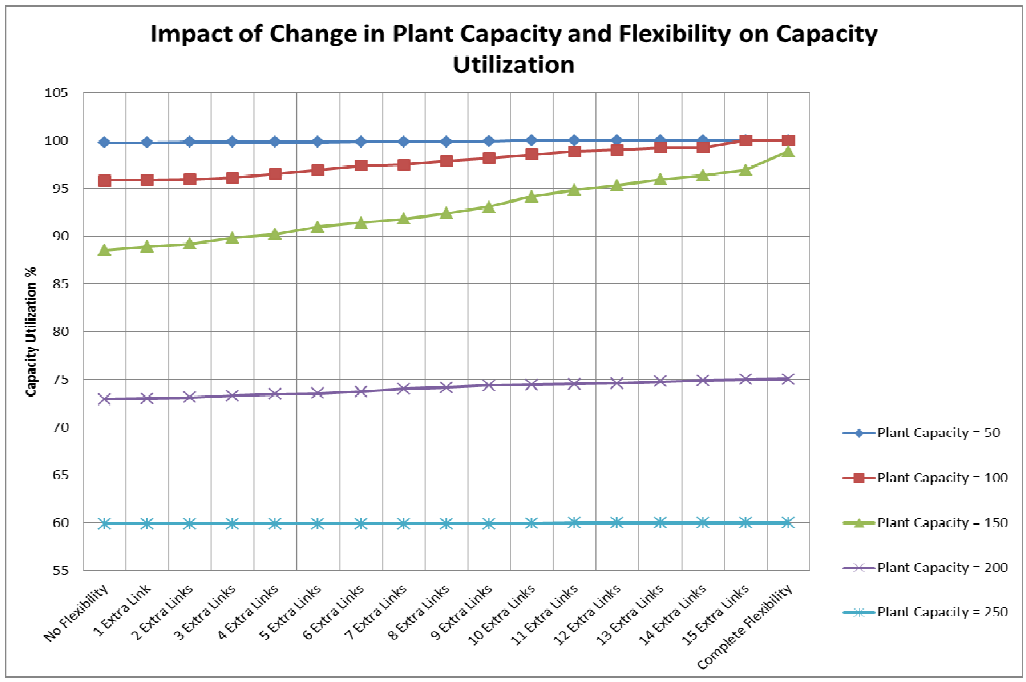

Figure 8: Impact of Change in Plant Capacity and Flexibility on Capacity Utilization

4.1.2. Changing the Standard Deviation of the Demand

In this case the standard deviation changes from 50 to 100, 150, 200 and 250, while other three factors remain in their default values. As can be seen from figures 9 and 10 higher the volatility in demand (i.e. higher the standard deviation), higher is the improvements in demand fulfillment and capacity utilizations percentages, with the increase in the number of links.

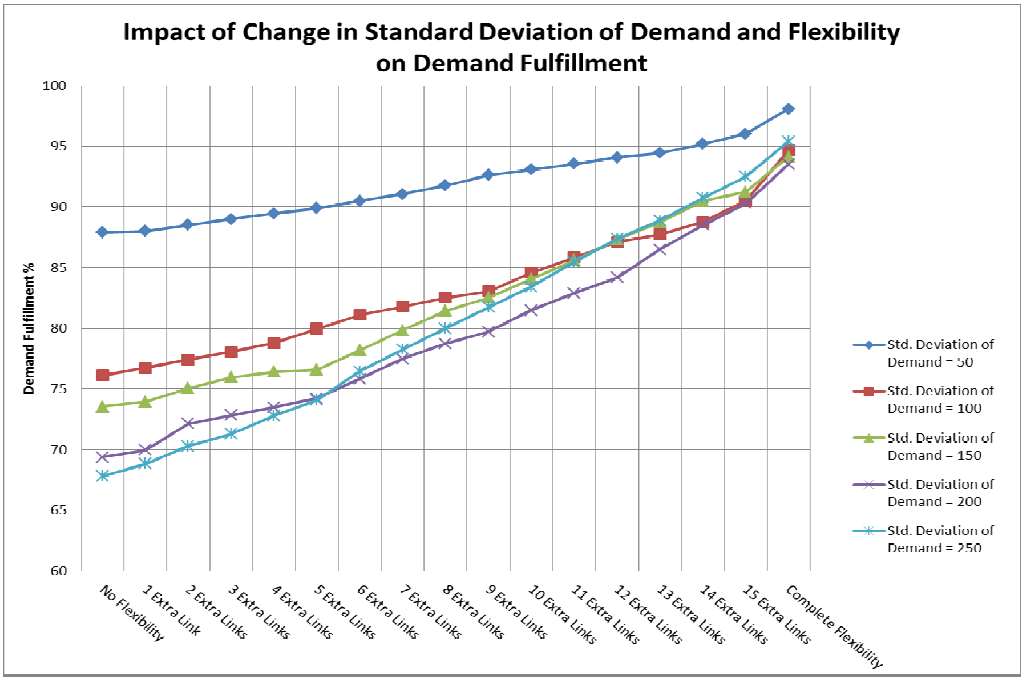

Figure 9: Impact of Change in Standard Deviation of Mean Demand and Flexibility on Demand Fulfillment

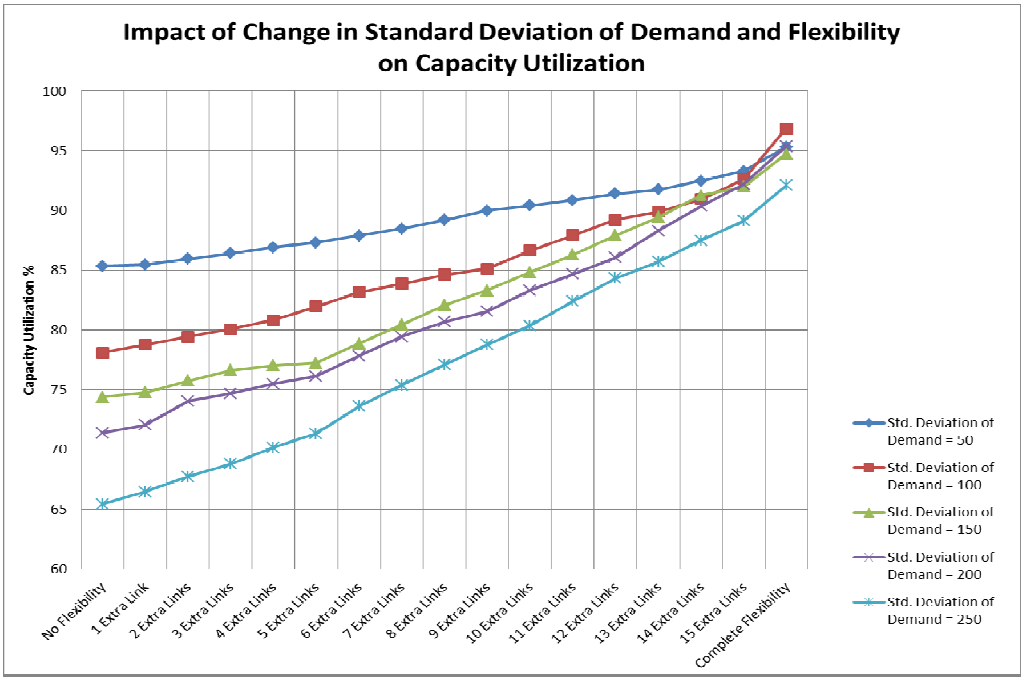

Figure 10: Impact of Change in Standard Deviation of Mean Demand and Flexibility on Capacity Utilization

Here average demand is set equal to the plant capacity. So, aggregate demand for the fifteen models of cars can be considered to be 2250 (@ 150 for each of the 15 models), that is equal to the total production capacity of the plants. Generally, aggregate demands can be forecasted fairly accurately. However, mismatches are created due to uncertainty inherent in the forecasts for demands of the individual models. There can be demands unfulfilled and capacities underutilized at the same time. The extent of this mismatch is determined by the size of uncertainty. For example in figure 9, when standard deviation of the demand is 50 (mean demand is 150), about 85% of

the percentage customer demand is fulfilled even without flexibility, then again when standard deviation rises to 250 that value drops to about 68%. Figure 10 shows similar effect with capacity utilization.

Similarly, when the demand is almost random, the standard deviation is very high. In such situations, process should be flexible for it to be able to cope with high levels of uncertainties. Figure 9 also shows improvements in the percentage of customer demand fulfillment, with every addition of link, is much more rapid when standard deviation is higher. This means, higher the standard deviation higher is the uncertainty, and higher is the improvements with addition of links [1, p 259]. This is the logic behind the original Jordan and Graves (1995) simulation.

Managers in Dell computers feel that they can forecast aggregate demands of components, such as key board, RAM, memory chips or different sizes of monitors for example, fairly accurately. These can be mass produced efficiently. However, they cannot forecast how each customer will combine these components to get their individualized computers. There is a high uncertainty here. Therefore, they need a very flexible assembly process. Such model which allows customers to buy individualized products, which seller provides by assembling standard mass produced components is known as "Dell model" [8, p 179-187; 9, Chapter 1; 7]. We can also argue that, unlike their competitors, Dell created uncertainty, by allowing customers to design their own computers, as a way of acquiring competitive advantage on the strength of their flexible operations.

4.1.3. Changing the number of plants

In this case the number of plants change from 5 to 10 to 15 to 20 and then to 25, while other three factors remain in their default values. The number of plants can also be construed as the number of models in garments for example. Or, it could even be number of varieties available for customers to choose from.

As can be seen from figure 11, when customers have five varieties to choose from, it needs five additional links to form a complete chain. And, this chain fulfills (almost) 95% of the customers' demand. And, when varieties increase to fifteen for example, it takes fifteen additional links to create a complete chain. However, after adding so much of complexity, this chain also fulfills just 95% of the demand. Therefore, varieties (models or available choices for customers) should only be added when adding them can lead to increase in sales and/or command premium in price. The gains, from new markets and premium pricing, should be higher than the cost of investing and operating for added flexibility.

There are examples, where adding varieties have added to the complexity and costs, without bringing additional benefits in terms of customer loyalty, increased sales or premium pricing. Auto industry has many such examples. With competition heating, companies bring up different models of cars in quick successions. Each model comes with multiple body styles and engines etc. Besides, there are wide ranges of options available (such as leather seats to types of stereos etc.) for the interior of a car, and varieties of colors to choose from for the exterior. All these varieties multiply and add to the complications for manufacturers. For example when all the options, colors and trim etc. available to customers on two Mercedes models available in UK are

considered the total number of varieties available added up more than a trillion. Most of the times, customers would not recognize the options available to them [3, p 165-166].

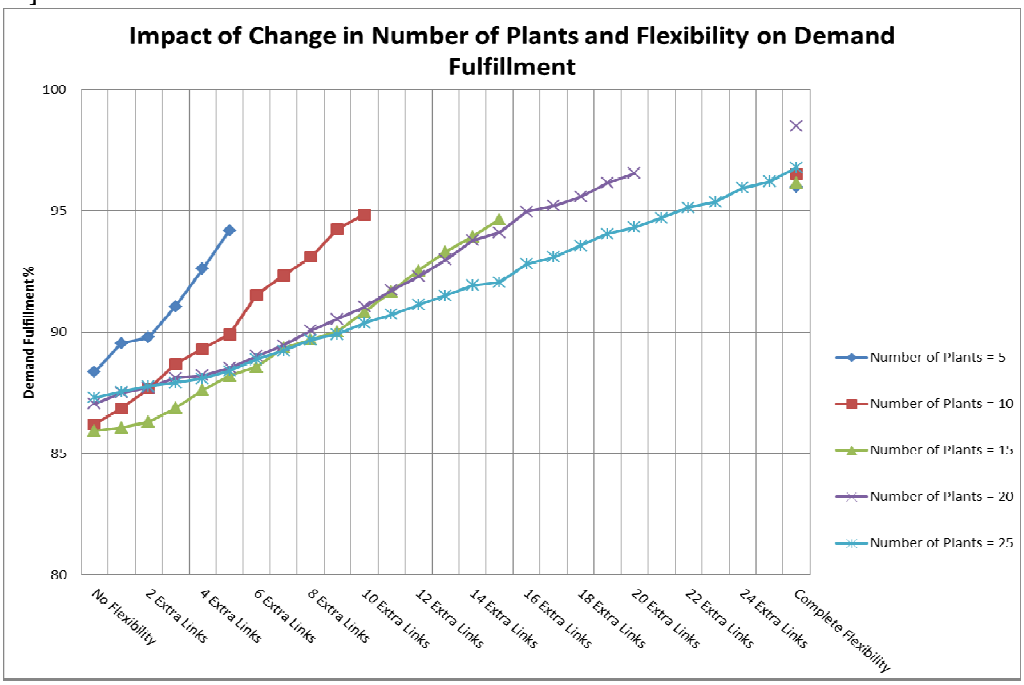

Figure 11: Impact of Change in Number of Plants and Flexibility on Demand Fulfillment

And, there are also examples where, by actually reducing the number of varieties, and focusing on what customers really want, companies gain new markets and growth opportunities. For instance, Yellow tail brand in wine increased sales by reducing the wine varieties, and making it simple for the customers to enjoy wine without having to understand the meanings of obscure terminologies used by wine connoisseurs [5]. In auto industry itself, Honda Accord, which is one of the very successful brand, gives its customer only about a thousand varieties to choose from [3, p 166].

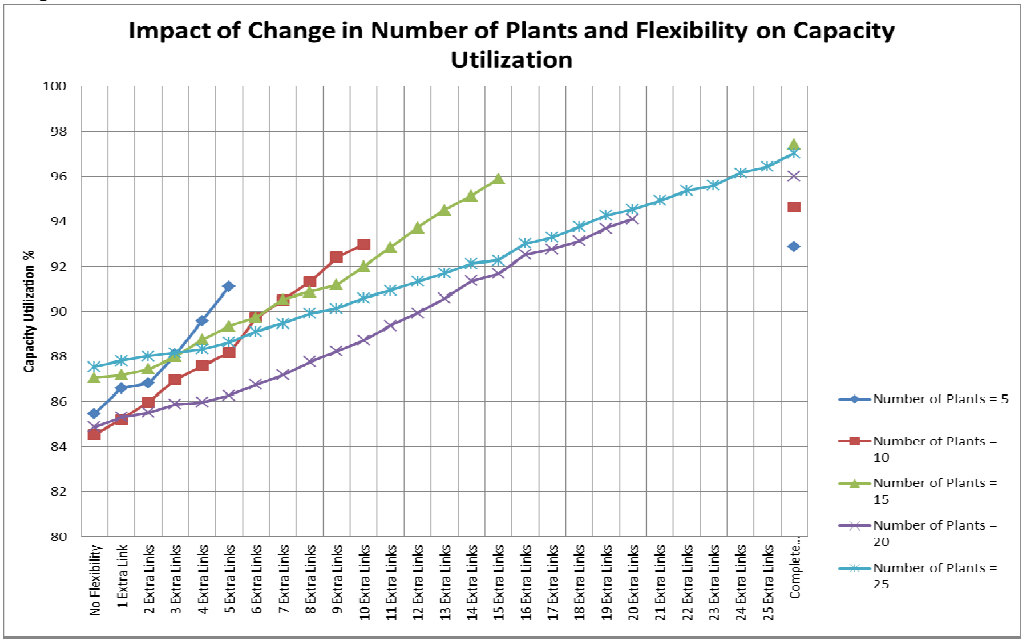

Figure 12: Impact of Change in Number of Plants and Flexibility on Capacity Utilization

Dell model, we discussed just now allows their customers to design their own computers, thus inserting uncertainties in demand. Availability of varieties and uncertainties in demands are related. However, Dell also limits the choice a customer can make at any one time by providing limited options to choose from. And, it also subtlety directs customers, by discounts and other incentives, to choose what it likes to sell urgently [9, p 179-187]. So, managing the uncertainty and complexity is very much part of the flexible operating system.

5. Conclusion

We developed two simulation programs, using the conceptual framework of the article by Jordan and Grave (1995). Given the flexible nature of this simulation, each experimenter can draw his/ her conclusion. Here are some of the general conclusions we drew on the basis of experiments in these simulations.

The first one (Flexibility Experiment.xlsm), allows experimenter to choose the values of four different factors- average demand, standard deviation of demand, plant capacity and number of plants, and see how demand fulfilled and plant utilization are impacted. This model allows students appreciate the concept of process flexibility and verify various process related issues discussed in text books as well as by Jordan and Graves (1995).

Flexible process allows plants with fixed capacity to cope with uncertainty in market demands. Such process increase capacity utilization and customer order fulfillment at the same time, by reducing the mismatch. However, how much flexible a process requires to be depends on the how much business gains by adding flexibility vs. how much it costs to create and run it. Most of the time complete flexibility is not necessary [1, p 344-349; 4].

Further, the extension (Flexibility Experiment11.xlsm), allows the experimenter to see the impact of change in one factor while keeping rest three constant. Thus, it extends the understanding of process flexibility, and leads toward few more inferences which are very relevant to management students, scholars and researchers. The first one is that flexibility can be gained by adding ability to plants to produce more than one items, or by adding extra capacities in the plants (allowing them to cope with the fluctuations in demands), or some combination thereof [1, p 171-172].

Besides we also saw that, uncertainty also depends on how many varieties (and model choices) a business offers to its customers. Providing optimal numbers of varieties, by weighing the needs of customers and the value they add to the cost of complexity in the business process, should be the target of any business. At the same time, unnecessary additions of models and variations, in the heat of competition, can only add to complexity leading to lower level of customer service. So, managing uncertainty should also be part of overall strategy pertaining to the process flexibility. The ability of this model (the extension part) to bring forth this important issue in the discussion of flexibility, when this fact was only obliquely discussed in business strategy contexts [for example 3, p 165-166; 5] is an important contribution of this paper.

Given the flexible nature of these models, and their availability to download along with this paper, can make it an import tool for students / scholars allow students and scholars to conduct their own experiment and draw their own conclusion. This can be considered another important contribution of this paper.

References

[1] Cachon G and Terwiesch, C (2009), *Matching Supply with Demand An Introduction to Operations Management*, Second Edition, McGraw-Hill Irwin

[2] Fujimoto, T (1999), The Evolution of A Manufacturing System at Toyota, Oxford University Press Inc.

[3] Holweg, M and Pil, F (2004), *The Second Century Reconnecting Customer and Value Chain through Build-to-Order*, Massachusetts Institute of Technology

[4] Jordan, W. C., & Graves, S. C. (1995). Principles on the Benefits of Manufacturing Process Flexibility. *Management Science*, *41*(4), 577-594.

[5] Kim, C and R Mauborgne (2005), Blue Ocean Strategy: From Theory to Practice, *California Management Review*, Vol. 47 Issue 3, p105-121

[6] Lawrence J and Pasternack B (1998) *Applied Management Science A Computer-Integrated Approach for Decision Making*, John Wiley and Sons

[7] Magretta J (1998), *The Power of Virtual Integration: An Interview with Dell Computer's Michael Dell*, Harvard Business Review, March-April, p 74-84

[8] Simichi-Levi, D (2010), *Operations Rules Delivering Customer Value though Flexible Operations*, The MIT Press (Kindle Edition)

[9] Simichi-Levi, D, Kaminsky, P and Simichi-Levi, E(2008), *Designing and Managing Supply Chain Concepts Strategies and Case Studies*, Third Edition, McGraw-Hill Irwin

[10] Swamidass, P. M., & Winch, G. W. (2002). Exploratory study of the adoption of manufacturing technology innovations in the USA and the UK. *International Journal Of Production Research*, *40*(12), 2677-2703

[11] Upton, D. M. (1994). The Management of Manufacturing Flexibility. *California Management Review*, *36*(2), 72-89.