



# Risk Management in Supply Chain using PetriNet

<sup>1</sup>Pranay Bhardwaj, <sup>2</sup>Prateek Singh, <sup>3</sup>Girish Kumar

Delhi Technological University

Email: <sup>1</sup>prnybhrdwj@gmail.com, <sup>2</sup>Prateek.dce14@gmail.com

**Abstract-** This paper is aimed at formalising an objective method to analyse and assess operational risk in a Supply Chain network. The proposed method exploits the analogy between the supply chain network and dynamical systems. We wish to identify the risky events characterising a general supply chain by constructing and studying its Petri Net. Here we have tried to simulate the Petri Net of the network through MATLAB so we can analyse the results to identify the risky events in the network and more importantly, the contribution of these risky events towards disruption of the system, i.e. stock-outs at the retailer end. We have applied the method to a single item, 3-stage Supply Chain and have tried to make the model more relevant by adding events such as partial-fulfilment of demand at the retailer stage and complete non-availability of transportation resources during scheduled servicing at the distributor and manufacturer stage, thereby making the model more robust and closer to reality.

**Index Terms**—MATLAB, Petri Net, Risk, Supply Chain

## I. INTRODUCTION

With the spread of Globalization and the advances in the field of communication and IT, this world has become a very small place, with various inter-connections. What it means for businesses around the world is that even small incidents in one part of the world can have big impacts on another part or the world at large. The well-known terrorist event of September 11, 2001 in USA led to the closure of US Air space, Hurricane Floyd flooded a Daimler Chrysler plant leading to closure of the company's 7 other plants across North America, Toyota was forced to shut down 18 plants for almost 2 weeks following a fire in 1997 at one of its brake fluid supplier, and many other such examples are present which have cost companies major losses in business because of small events that disrupted the supply chain. Managing supply chains in today's competitive world is increasingly challenging. "The greater the uncertainties in supply and demand, globalisation of the market, shorter and shorter product and technology life cycles, and the increased use of manufacturing, distribution and logistics partners resulting in complex international supply network

relationships, have led to higher exposure to risks in the supply chain." [11]

With the broad aim of studying these risks inherent in a supply chain, our team decided to focus on the supply chain in its simplest form and study the areas where a disruption will have maximum effect on the whole supply chain at large. Being engineering graduates, we are trying to model a distributed system like supply chain by adding mathematical rigour to it. For the same purpose, we have modelled a simple 3-tier supply chain through Petri Net. Later we realized that the present work available on the same is considering only complete fulfilment of the demand as the basis of measurement of supply-demand dynamics. However, in real world, we also have partial fulfilment of demand as an alternative for lack of supply in comparison to demand. Keeping that in mind, our team tried to re-model the Petri Net to include partial fulfilment of the orders. The same has been presented in this project report. The attempt still lacks mathematical rigour as the model is very complex. However, we have succeeded in getting a graphical representation of the same that satisfies the basics.

MATLAB has been used to simulate the Petri Net model. The report presents the findings of the simulation of the model with partial-fulfilment. Our results have shown a considerable decrease in the total number of completely unsatisfied customers and the results are consistent over a large number of iterations.

We would also like to bring to the attention of the readers of this report that while Supply Chain risk management includes various kinds of risks, we, with the aim of simplifying the whole thing for simulation, are focussing only on Stock-outs and Bull-whip effect due to information distortion, transport line breakage and production disruption. The elements considered in this simplified 3-tier supply chain are restricted to Customer-Retailer-Manufacturer-Supplier and the Transport system connecting them all..

## II. METHOD

In real life, a customer is not always necessarily classified as ‘satisfied’ or ‘unsatisfied’. In many industries, the customer orders for partial fulfilment of demand in case the stock level is low for complete fulfilment. This is an important aspect that will give a better picture of the risks inherent in Supply Chain.

Moreover, the transport model linking the manufacturer-wholesaler and wholesaler-retailer also can be made closer to reality by adding the fact that availability of transport also varies because the need for servicing and the rate of failure varies with time. These problems are the main points of concerns that have been addressed by this project report.

### The Proposed Approach

The proposed approach for simulating the Supply Chain operating without any biased deficiencies consists of applying Petri Net and then simulating it in MATLAB. Firstly, the Petri Net corresponding to the theoretical supply chain under study is built. The disruptions the system can suffer are of two kinds. The more harmful disruptions are in the form of totally unmet demand. The less harmful disruption to the system comes from partially met demand. While building the Petri Net, it is important to put in the net some places which do not correspond to any physical element of the network but record, through the tokens they contain, the number of times the disruptions of each kind has occurred. By means of the reachability graph of the considered Petri Net, sequences of fired transitions which enable marks characterized by tokens in the above mentioned places can be determined and hence, risky events can be identified.

Phase	Technique	Tool
Risk Analysis	Dynamic System modeling and control	Petri Net Reachability Graph (MATLAB)
Risk Assessment	Simulation Statistical Analysis	Event Driven Simulation ANOVA/MATLAB

Table No. 3

If there are n risky events the network can suffer from, n+1 experimental campaign have to be performed on the network. Once when no risky event happens and then in other n experiments, each risky event is taken into account separately.

### THE NETWORK

To contain the level of complexity, a single item 3-stage supply chain is considered. In particular network consists of 1 retailer, 1 distributor and one manufacturer. Concerning the retailer, it should be noted that the replenishment policy referred to is the EOQ model modified according to the forecast system.

The elements characterizing the retailer are:

1. Daily demand (Given by the customer arrival time and the customer demand. Customer arrival time fits into an exponential distribution. Customer demand is probabilistically chosen from a set of empirical data)
2. Level of partial satisfaction of customer (In case of failure at the end of the retailer to meet the customer demand, a random number X is generated from a distribution.  $X \in (1,100)$ . X gives the percentage of original demand acceptable to the customer. The value of acceptable quantity A is given by:  $A = (Xxd)/100$ , where d represents the original demand. If  $A \leq M(P6)$ , the entire inventory is emptied and the goods are given to the customer)
3. Economic reorder quantity (Depends upon retailer forecast)
4. Reorder point (Depends upon retailer forecast)
5. Safety stock (Depends upon retailer forecast)
6. Standard and increased delivery time (represented by the probability distribution of the time the retailer has to wait to receive goods both under normal circumstances and when some problems occur)
7. Forecast horizon
8. Forecast accuracy

The distributor too manages his inventories according to the EOQ model. The difference at the level of the distributor comes when we have to model transportation availability. Moreover, the distributor does not get a daily demand. The demand is given by retail orders. The parameters to be considered at the level of the distributor are:

- Initial inventory
- Economic Reorder Quantity (EOQ)
- Reorder point
- Safety stock
- Transportation availability (failure of transportation and the subsequent repair is built into the structure)

- Standard and increased delivery lead time (From the manufacturer)
- Forecast horizon
- Forecast accuracy
- The manufacturer produces goods through predefined production campaigns. The important parameters for the manufacturer are:
- Availability of transportation (Failure and repair is built into the Petri Net)
- Availability of production resources
- Lot sizing policy
- Production lead time
- Time interval two production campaigns
- Inventory

**SUPPLY CHAIN PETRI NET**

The place P1 and the transition T1 allow customer arrival to be modelled. Whenever there is a token in P1, T1 fires after a duration drawn from the probability distribution of customers' inter-arrival times. The firing of T1 removes the token from P1, generates a token in P2 with an attribute *d*, a value drawn from the empirical distribution of the number of items bought by a single customer and it simultaneously also generates a token in P1. The transition T3 is fired if the number of tokens in P6 is greater than or equal to *d*, i.e. if  $M(P6) \geq d$ . If T3 fires, one token is removed from P2 and one token is generated in P4, recording the number of satisfied customers and one token is created in P5. As soon as the token is generated in P5, T7 fires, removing one token from P5, *d* tokens are removed from P6 and one token is generated in P8. T9 fires when the marking of P6 (the number of tokens in P6) is less than ROP, i.e. the Re-order Point, creating a token in P12 and removing the token from P8. Otherwise T8 fires and removes the token from P8, dumping the token in P11.

If the demand created by the customer is more than the number of tokens in P6 ( $M(P6) < d$ ), T2 fires creating a token in P3. Depending upon whether the stock level is acceptable to the customer or not, T4 or T6 fires. The probability of acceptance of stock level is proportional to the percentage of demand being fulfilled. T4 fires if the customer accepts the stock level and T6 fires if it is not.

When T4 fires, it removes the token from P3 and creates one in P7. Whenever there is a token in P7, T5 fires instantaneously removing  $M(P6)$  tokens from P6, generating a token in P10, which records the number of partially satisfied customers and one token in P12, indicating that it has placed an order with the distributor

when T6 fires, it removes the token in P3 and creates one in P9, which records the number of dissatisfied customers.

Whenever there is a token in P12, P23 (indicating availability of transportation) and the EOQr (Economic Order Quantity of the Retailer) quantity is present in the distributor warehouse P13, T10 fires, removing the token from P12, EOQr tokens from P13, and creates one token in P27 and EOQr tokens in P6 after a duration drawn from the distribution of distributor delivery lead times. Simultaneously, it creates a token in P24, which records the number of trips completed since the delivery vehicle underwent its scheduled servicing. If the delivery vehicle hasn't been taken in for servicing (there is a token in P23), the availability of transportation resource is  $0.8 \cdot M(P24)$  (equal to the number of trips completed since the last scheduled servicing) is greater than 1 and less than 10. Otherwise, it is 0.7. If the vehicle is deemed unavailable even if there is a token in P23, the delivery time generated is normally distributed with mean equal to 2 days and standard deviation 0.6 days. If the transportation resource is available, the delivery time generated is normally distributed with mean equal to 2 days and standard deviation 0.5 days. T10 fires after the delivery time generated in this process.

The transportation availability of the distributor is modelled in the Petri Net. When a token is in P23 and no token is present in P12 (indicating the retailer hasn't placed an order), T20 after 90 days creating a token in P25. Whenever there is a token in P25, T19 fires after a time which is normally distributed with mean equal to 2 days and mean 0.5 days (to model the time taken up in servicing the vehicle). This removes  $M(P24)$  token from P24, thereby resetting the trip meter, one token from P25 and generates one token in P23 and one token in P26 which counts the number of times the vehicle underwent scheduled servicing.

	Element	Expression Value
<i>Retailer</i>	Customers inter-arrival time	Exp(0.0069) [days]
	Items bought by the single customer	Disc(0.5,1,0.8,2,0.95, 3,1, 10) [units]
	Initial inventory (R)	650 [units]
	Economic order quantity (EOQr)	$(2 \cdot 100 \cdot D_r / 3.5 \cdot 0.005) / 2$
	Re-order point (ROPr)	$(D_r / 15) \cdot 2 + SS$
	Safety stock (SSr)	$1.96 \cdot [(D_r / 15) \cdot 2 \cdot 0.52 + 2 \cdot (1.25 \cdot MAD) \cdot 2] / 2$
	Supplier delivery lead time	norm(2,0.5) [days]

	(standard)	
	Supplier delivery lead time (non-standard)	norm(2.5,0.6) [days]
	Forecasting horizon	15 [days]
	Forecast accuracy	0.9
Distributor	Initial inventory (S)	1100 [units]
	Economic order quantity (EOQd)	$(2*100*Dd/2.5*0.015)/1/2$
	Re-order point (ROPd)	$(Dd/3)*0.13+SS$
	Safety stock (SSd)	$1.96*[(Dr/3)^2*0.032+0.13*(1.25*MAD)^2]^{1/2}$
	Transportation resource availability	0.8
	Supplier delivery lead time (standard)	norm(0.13,0.03) [15days]
	Supplier delivery lead time (non-standard)	norm(0.17,0.04) [15days]
	Forecasting horizon	45 [days]
	Forecast accuracy	0.9
Manufacturer	Initial inventory (U)	20000 [units]
	Lot size (LS)	30000 [units]
	Time intervals among 2 campaigns (IC)	40 [days]
	Production lead time	5 [days]
	Production resource availability	0.8
	Transportation resource availability	0.8

Table No. 4 – Synthetic view of considered supply chain [7]

T11 fires when there are less than ROP\_D tokens in P13. It eliminates M(P27) tokens from P27 and generates a token in P14. T12 fires whenever there is a token in P14, P16 (representing availability of transportation at the manufacturer end) and more than EOQ\_D number of tokens in P19 after a duration drawn from the manufacturer delivery lead times generating EOQ\_D tokens in P13, one token in P15, removes one from P14 and EOQ\_D tokens from P19. The transportation availability at the manufacturer is modelled as it was at the distributor.

The modeling of the production campaign of the manufacturer is as follows. Whenever there is a token in P22 (implying availability of raw materials for manufacturing), T18 fires after a 5 days (which is the production lead time). The firing creates LS (Lot Size) tokens in P19, and one token in P20. This activates T15 which fires after IC(40) days. IC is the number of days between successive production campaigns. Firing of T15 generates a token in P21. Depending upon whether production resources are available or not, T16 or T17 fires. T16 fires if the resources are not available and T17 fires if they are. The probability of T17 firing is 0.8. Otherwise T16 fires after one minute generating a token in P21 again. Firing of T17 creates a token in P22 indicating that production resources are now available.

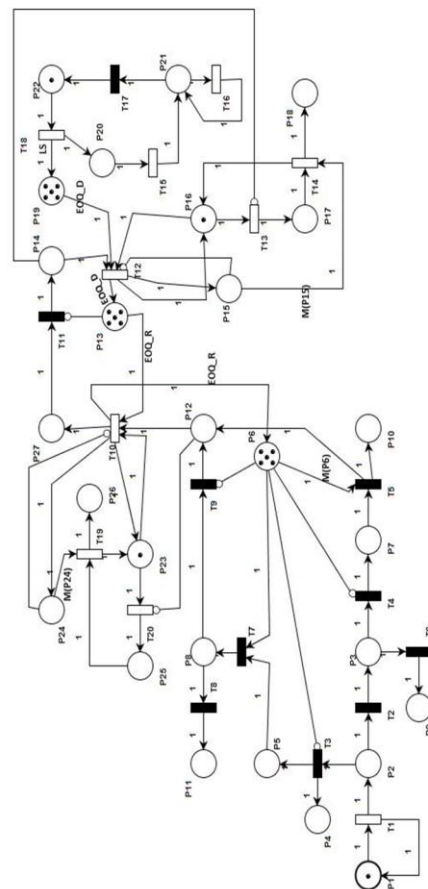


Figure 10

**Algorithm Used**

1. Customer arrives at the retail store. Arrival interval is distributed exponentially.
2. Customer creates a demand d.
3. Retailer checks the warehouse level to see if the demand can be fulfilled.

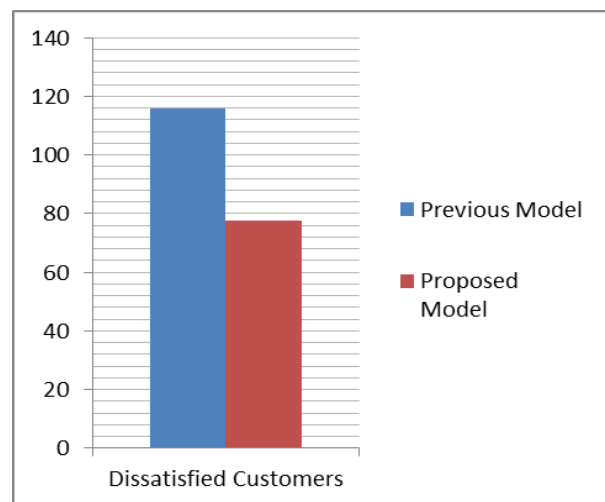
4. If the demand can be fully met, the customer is satisfied; warehouse level goes down by the value of his demand.
5. If the demand cannot be fully met, the percentage of demand being fulfilled is equal to the probability of acceptance of warehouse stock by the customer.
6. If the customer in such a case finds the warehouse stock acceptable, he is assumed to be partially satisfied. Otherwise, he is assumed to be a dissatisfied customer.
7. The retailer compares his warehouse level after every customer with his re-order value. If he finds it less, he places an order with the distributor provided he hasn't done so already.
8. The distributor, on receiving an order from the retailer, checks his inventory level and transportation availability. If the demand can be met and the delivery vehicle has not been sent for scheduled servicing, a normally distributed delivery time is generated.
9. When the time elapsed since the retailer re-ordered becomes equal to the delivery time generated, the retailer demand is fulfilled. The distributor inventory reduces by the same level.
10. After every order, the distributor checks his warehouse. If the inventory level is less than his re-order point, he places an order with the manufacturer provided he hasn't done so already.
11. The manufacturer on receiving an order from the distributor looks at his inventory level and transportation availability. If the inventory level is sufficient to meet the demand and the delivery vehicle has not been sent for scheduled servicing, a normally distributed delivery time is generated.
12. When the time elapsed since the distributor re-ordered becomes equal to the delivery time generated, the distributor demand is fulfilled. The manufacturer inventory reduces by the same level.
13. The manufacturer runs a production campaign every 40 days provided production resources are available. The lot size is 30000 and the campaign lasts 5 days.
14. Running simultaneously are the models for transportation availability at the distributor and the manufacturer. They are scheduled for servicing once every 90 days provided their customer in the Supply Chain hasn't placed an order. After every delivery, the trips completed by the delivery vehicle are increased by 1. The number of trips completed is reset after servicing. The availability of transportation resource is 0.8 if the trips

completed lie between 1 and 10. Otherwise it is 0.7.

15. This Supply chain model is run for 180 days an n number of times and the number of satisfied, partially satisfied and dissatisfied customers are plotted against the number of iterations. The number of dissatisfied customers gives a measure of the inefficiency of the system.

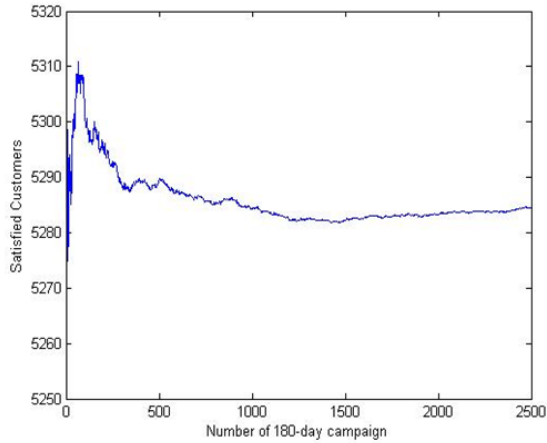
### III. RESULTS

The modified Petri Net with the addition of partial fulfilment of customers improves the efficiency of the supply chain. The percentage of 'dissatisfied' customers comes down from 2.193% to 1.461%. Therefore the efficiency of the supply chain improves by 0.718% and the level of 'dissatisfied' customers is reduced by 32.89%. Not being able to meet the customer demand at the level of the retailer is the only disruption the supply chain is supposed to refer to.

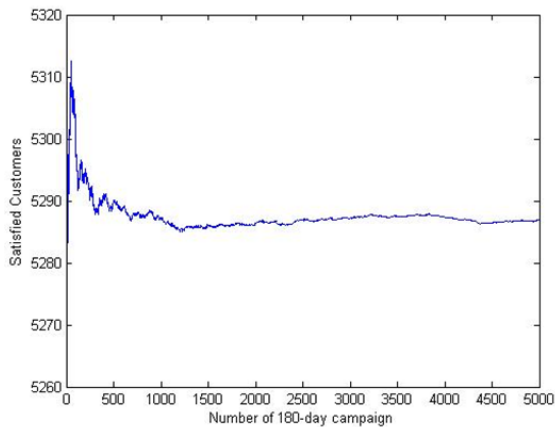


**Figure 11** Comparison of models for number of satisfied customers and unsatisfied customers at the end of simulation

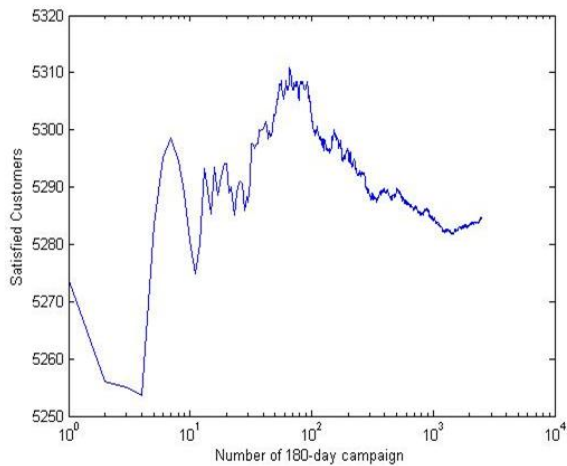
Comparison of the previous model and the proposed model has been done using Monte Carlo simulations. Satisfied, Unsatisfied and Partially-satisfied customers have been plotted against time interval in a 180 day campaign. Simulation Results from MATLAB are given below.



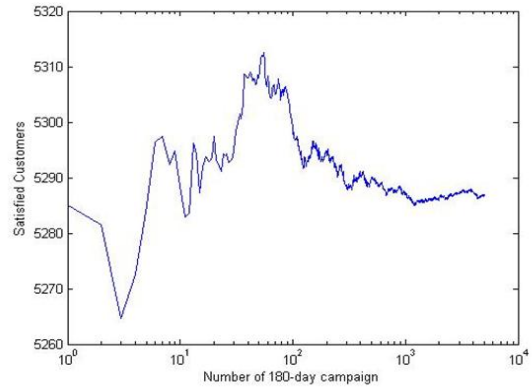
(1) Satisfied customers in previous model



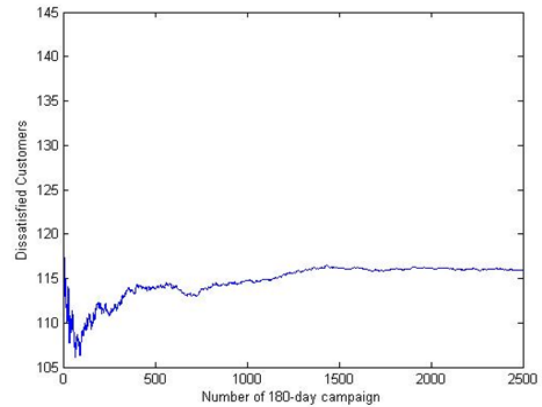
(2) Satisfied customers in proposed model



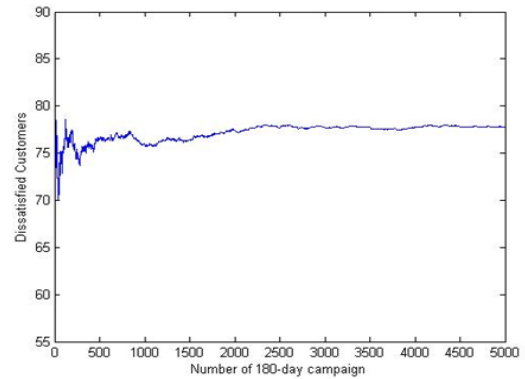
(3) Semi log plot of previous model



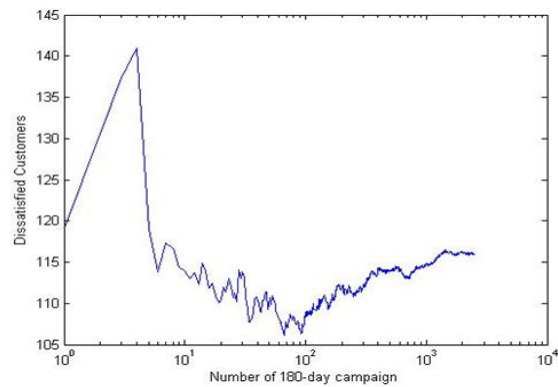
(4) Semi log plot of proposed model



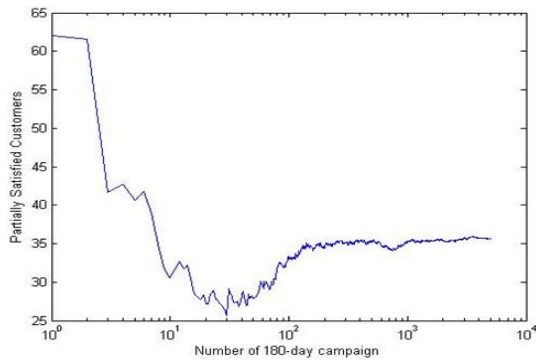
(5) Dissatisfied customers in previous model



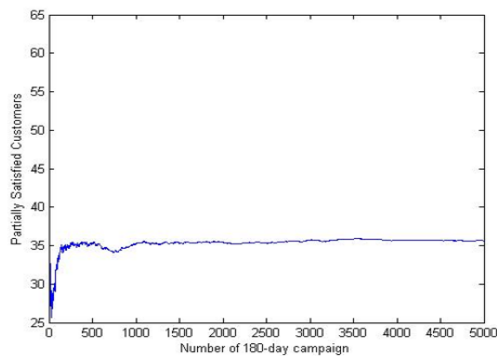
(6) Dissatisfied customers in proposed model



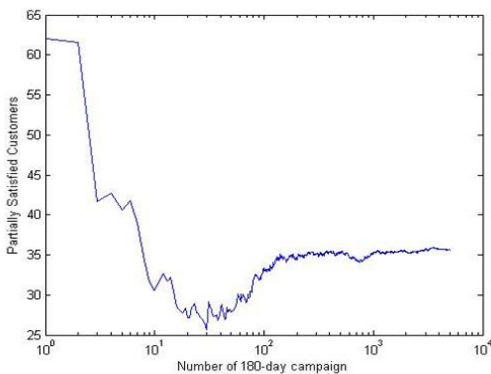
(7) Semi log plot of previous model



(8) Semi log plot of proposed model



(9) Partially satisfied customers



(10) Semi log plot of partially satisfied customers

Figure 12 Comparison of MATLAB simulation graphs for 180-day campaign

#### IV. CONCLUSION

The model we built for the supply chain mirrors the actual world better than the models available previously. Therefore the risk factors identified by our model will be more relevant in the real world and would be a better diagnosis of the problems that the Supply Chain faces. The efficiency of the supply chain increases by introducing the clause of partial fulfilment of demand at the retailer stage but delivery times get worse by making the model more real as we have incorporated scheduled servicing of delivery vehicles. Overall, the Supply chain has become more efficient by 0.7% (approximately) and relatively, the efficiency of the supply chain goes up by about 33%.

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