Information Sharing for improved Supply Chain Collaboration – Simulation Analysis

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A Thesis

In the

Concordia Institute for Information Systems Engineering (CIISE)

Presented in Partial Fulfillment of the Requirements for the Degree of

Master of Applied Science (Quality Systems Engineering) at

Concordia University

Montreal, Quebec, Canada

June 2019

Concordia University

School of Graduate Studies

This is to certify that the thesis prepared

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Entitled: **Information Sharing for improved Supply Chain Collaboration – Simulation Analysis**

and submitted in partial fulfillment of the requirements for the degree of

Master of Applied Science (Quality Systems Engineering)

complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

Information Sharing for improved Supply Chain Collaboration
– Simulation Analysis

Suganya Jayapalan

Collaboration among consumer good's manufacturer and retailers is vital in order to elevate their performance. Such mutual cooperation's, focusing beyond day to day business and transforming from a contract-based relationship to a value-based relationship is well received in the industries. Further coupling of information sharing with the collaboration is valued as an effective forward step. The advent of technologies naturally supports information sharing across the supply chain. Satisfying consumers demand is the main goal of any supply chain, so studying supply chain behaviour with demand as a shared information, makes it more beneficial. This thesis analyses demand information sharing in a two-stage supply chain. Three different collaboration scenarios (None, Partial and Full) are simulated using Discrete Event Simulation and their impact on supply chain costs analyzed. Arena software is used to simulate the inventory control scenarios. The test simulation results show that the total system costs decrease with the increase in the level of information sharing. There is 7% cost improvement when the information is partially shared and 43% improvement when the information is fully shared in comparison with the no information sharing scenario. The proposed work can assist decision makers in design and planning of information sharing scenarios between various supply chain partners to gain competitive advantage.

Acknowledgements

My learning experience in this thesis has been a very remarkable one and I would like to foremost acknowledge Dr. Anjali Awasthi for her continuous guidance and mentoring. Her frequent feedback has been beneficial in improving my models, experimenting and exploring new boundaries. Thank You Professor it has been my pleasure to work with you.

Also, I would like to mention the continuous support extended by my family and friends. My parents and sister have imparted me with immense motivation and encouragement at all times.

Last but definitely not the least thanks to my immediate friend Gayathri who has been around and has been my source of moral support throughout this academic journey of mine.

Thank You All!

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List of Acronyms

Acronym	Description
DES	Discrete Event Simulation
EDI	Electronic Data Interchange
CPFR	Collaborative Planning, Forecasting and Replenishment
JIT	Just In Time purchasing
VMI	Vendor Managed Inventory
IS	Information Sharing
ADI	Advance Demand Information Sharing
NIS	No Information Sharing
PIS	Partial Information Sharing
FIS	Full Information Sharing
TC	Total Costs
SCM	Supply Chain Management
DC	Distribution Center
WH	Warehouse
DP	Demand Planning

CHAPTER 1:

INTRODUCTION

1.1 Background

In order to stay competitive in the market, most organizations are gradually understanding the need for collaboration among different supply chain entities. Consistent higher profits and end customer satisfaction are the key driving factors for an efficient supply chain and a collaborated supply chain is an undeniable solution towards it (Srivathsan & Kamath, 2018). Among the many frameworks and strategies available for collaboration, Information Sharing within the supply chain is found to have reaped considerable benefits. Advent of technology like electronic data interchange (EDI) has aided this concept and the supply chain members find it fruitful when integrated together. When it comes to collaborative techniques, organizations are looking forward to adopt tools like collaborative planning, forecasting and replenishment (CPFR), just in time purchasing (JIT) and vendor managed inventory (VMI) (Park et al., 2010). Once the collaboration strategy is identified, the right information can be shared up the stream, bringing down any risks and uncertainties while expanding profits and customer satisfaction. There are many information's that is beneficial when shared across the chain, but the demand is the most significant one. The thesis addresses this topic and studies how the total costs decrease when demand as an information is shared.

Simulation is about replicating the real-world events over time using computer or physical models. Simulation models have been used to understand the processes in many domains like healthcare, aeronautical, etc. including supply chains (Rossetti, 2015). Inventory management in a supply chain is a very important but complex process particularly with stochastic demand from consumers. It can be modelled as discrete or continuous distribution making it an ideal entity to be evaluated via simulation. There are various simulations in use nowadays but a stochastic consumer demand in supply chain could be well studied via Discrete Event Simulation. Also, Arena being a popular simulation tool, is identified and used for modeling the supply chain collaboration models.

1.2 Problem Context

According to (Chang and Makatsoris, 2001) the phrase Supply Chain Management came up in the early 1990's as a process of integrating the supply chain members so that the goods are produced in the right amount, at the right place, at the right time while in parallel satisfying the customer and keeping the cost to the minimum. A typical supply chain is presented in Figure 1. It consists of various organizations involved from the supplier to the customer (Chang and Makatsoris, 2001).

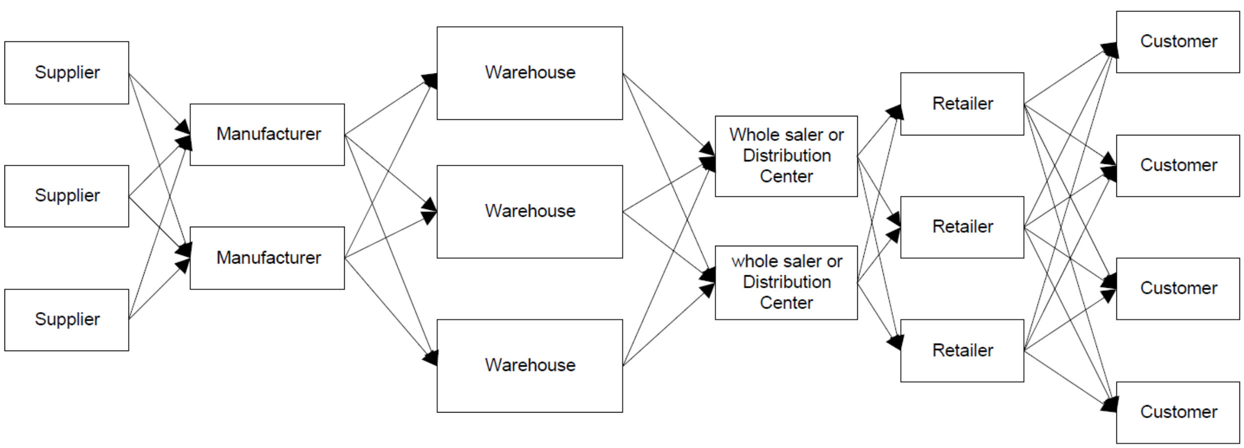


Figure 1: A Typical Supply Chain (Source: Chang and Makatsoris, 2001)

(Faisal et al, 2006) suggest that a traditional supply chain system does not focus on waste elimination. They further share that traditional supply system meets uncertainties in its information or material flow by means of buffer goods which is met at higher costs and are very slow in its response to demand changes. The authors advocate that these issues are mainly due to the lack of collaboration and information sharing between the supply chain members.

From the typical supply chain network understanding from (Chang and Makatsoris, 2001), it is very evident that a supply chain network is highly complex in nature and if not managed appropriately could lead to two main issues of high cost which in turn result in a low profit and unsatisfied customers which may basically lead to lost business/sales.

Also, from (Faisal et al, 2006) studies, traditional supply chain incurs high cost and lost customer satisfaction as they work as independent entities with no information sharing between them. This thesis will demonstrate how a collaborated supply chain, with sharing of information up the stream is able to minimize its operational cost, which could also thereby eventually transform a traditional supply chain network to an agile supply chain network.

1.3 Thesis Objective

This thesis intent would be to demonstrate the value increase in the supply chain when the level of collaboration is improved. With Demand as the control factor, the total cost reduction in the supply chain is studied. Discrete Event Simulation (DES) methodology is applied and an analysis of the performance parameters based on the input controls is done. The simulation models shall output supply chain performance with collaboration at three levels as shown in Figure 2:

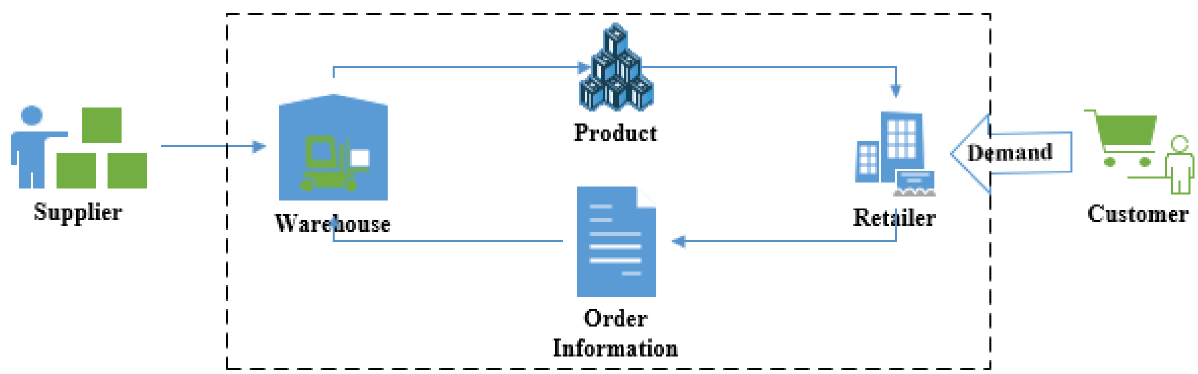
No Information Sharing (NIS): There is no flow of any Information from the Retailer to the Warehouse. The Warehouse receives its orders from the retailer whenever it is reorder time for the retailer. This model is considered as the Baseline Model.

Partial Information Sharing (PIS): Here there is a Partial Information Share from the Retailer to the Warehouse. The Consumer demand is given to the Warehouse in advance before the retailer places his order with the Warehouse.

Full Information Sharing (FIS): Here the consumer demand is placed directly to the Warehouse and retailer becomes a facilitator. Warehouse takes full control of the information and replenishes the order.

In addition, the models implemented would give a reasonable view on

- how traditional supply chain efficiency could be improved
- Total Supply chain cost improvement with increased level of information share



No Information Share

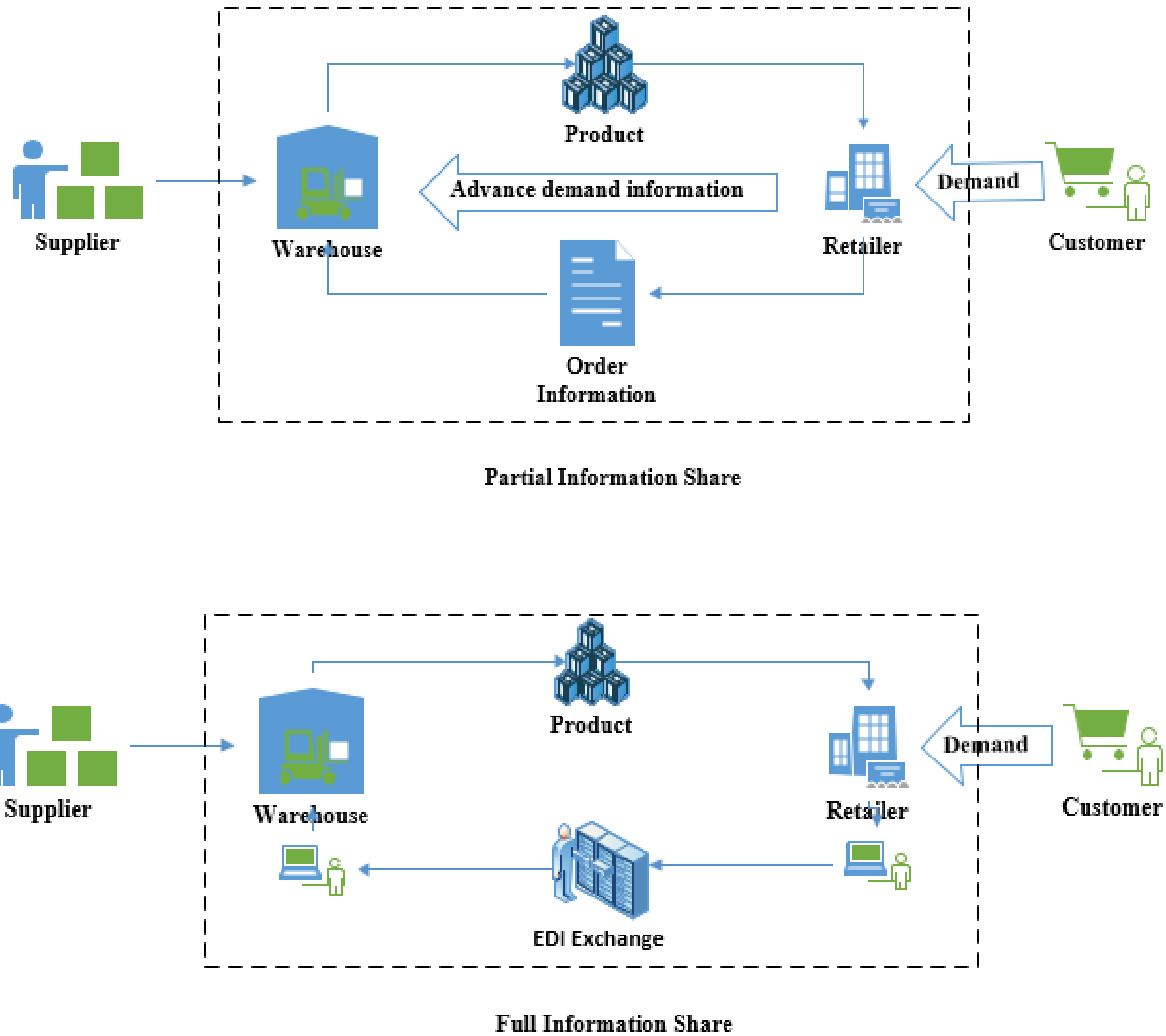


Figure 2: Information Sharing Scenario

1.4 Thesis Organization

This thesis has been structured in the following manner:

Chapter 2 – provides literature on the topics of supply chain collaboration, information sharing, queue information sharing, vendor managed inventory, discrete event simulation and Arena.

Chapter 3 – presents the solution approach. It covers the discrete event simulation process, conceptual model and detailed steps in which the simulation model was executed and results generated.

Chapter 4 – presents the model adaptation and implementation in Arena. This chapter provides all necessary information on how the model was adapted and executed using the Arena software all steps and procedures with respect to it has been explained here.

Chapter 5 – presents the numerical evaluation. The models developed are evaluated by a case study. Detailed numerical example and verification and validation of the model results are provided. Also, the sensitivity analysis is included to determine the impact of input parameters on final results.

Chapter 6 – presents the conclusion and future works. This section gives the final summary of the research in connection to the objective and on topics of future research.

CHAPTER 2:

LITERATURE REVIEW

2.1 Introduction

In this chapter, research available on the topic is reviewed and discussed. Section 2.2 describes the supply chain collaboration. Section 2.3 discusses Information Sharing and how it is seen as key enabler to supply chain collaboration. This section further elaborates on two topics, one being advance information sharing (a priori) which helps in partial collaboration and the other topic is on vendor managed inventory which is aligned to a full collaboration scenario. In section 2.4 the research and available information on inventory model decisions has been vividly detailed. Finally, section 2.5 brings out the literary work with respect to why discrete event simulation, since the approach has been embraced as a methodology is used to evaluate the objective.

2.2 Supply Chain Collaboration

Industries seeking to be ahead in the competitive world, have been evolving, by adopting new methodologies as early as from the nineteen century. In that era, work process integrations and optimizations were brought in by concepts such as lean production or just-in-time (Hopp and Spearman, 2011). After that supply chain collaboration has been the norm to share knowledge and to work integrated for an effective flow of products to the consumers (Caridi et al., 2005)

(Simatupang and Sridharan, 2002) in their research have defined supply chain collaboration as two or more supply chain member operating together by means of information sharing, mutually sharing benefits and looking to take joint decisions, so that high profits could be gained coupled together with greater level of end customer satisfaction.

There are different ways in which collaboration could happen and there are two distinct categories under which they could be encompassed - as per the review done by (Barratt, 2004). The first one is the vertical collaboration which includes the internal collaboration within supply chain members and external collaboration with suppliers or customers. The second one is horizontal collaboration which includes the collaboration between the external competitors or other organizations (Barratt, 2004).

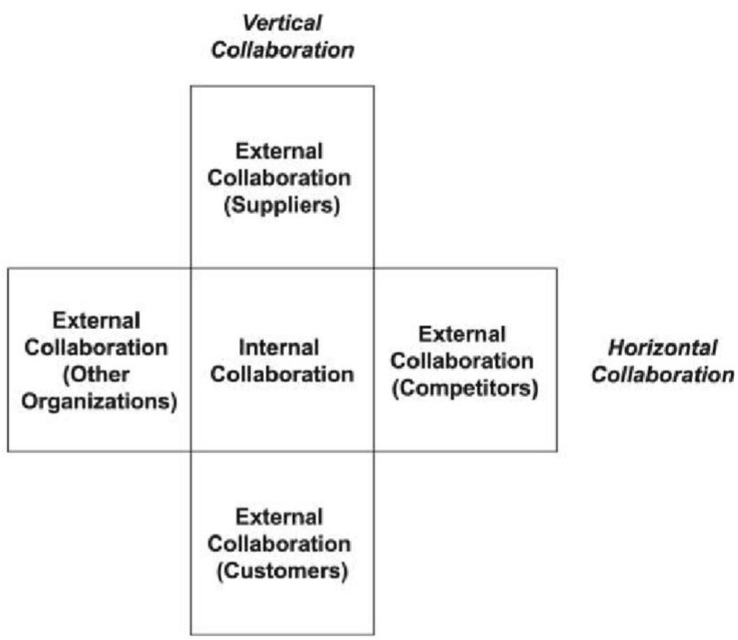


Figure 3: The scope of collaboration: generally (Source: Barratt M, 2004)

He has understood this flow from research done by (Simatupang and Sridharan, 2002) and consolidated it in in Figure 3 (Barratt, 2004). The thesis shall focus on internal collaboration which is a collaboration between the internal supply chain functions only.

Supply chain collaboration however is greatly challenged by the ever-fluid state of the global economic conditions, which leads us to believe whether it is successful or not (Magnan and

Fawcett, 2002). From the various surveys and case study interviews, it is understood that very few companies have been able to integrate their supply chain successfully, also their study indicates that there are gaps between the theoretical and the ideal world (Magnan and Fawcett, 2002).

(Kohli and Jensen, 2010) had undertaken to measure the effectiveness of collaboration by studying the existing available literature and among their various inferences, a conclusion states that the effectiveness of collaboration is perceived to be high when there is information sharing between the supply chain members which leads the chapter to discuss more on information sharing further.

2.3 Information Sharing

(Simatupang and Sridharan, 2002) describe information sharing as the bidirectional flow of information between the supply chain members thereby giving all the necessary insight across the internal functions and organizations. The authors also clarify that information sharing across the members lead to high customer service.

When it comes to what type of information could be shared, (Lotfi et al., 2013) there are many types such as on logistics, business, strategic, tactical and so on. The authors have also mentioned information categories such as 1) Inventory Information; 2) Sales Data; 3) Sales Forecasting; 4) Order Information; 5) Product Ability Information; 6) Exploitation Information of New Products; and 7) Other Information (Lotfi et al., 2013).

(Lotfi et al., 2013) have researched in detail and came up with a comprehensive table summarizing the benefits of information sharing in supply chain. Table 1 is an extract from their research that gives a good view on the benefits reaped when there is information sharing in the chain. Also, further benefits as reviewed has been adapted and presented in the table 1.

S.Nos	Benefits	Sources
1	Inventory reduction and efficient inventory management	(Prakash et. Al., 2010)
2	Cost reduction	(Prakash et. Al., 2010)
3	Increasing visibilities (significant reduction of uncertainties)	Ali et al., 2017
4	Significant reduction or complete elimination of bullwhip effect	(Hussain & Saber,2012) (Jauhari,2009)
5	Improved resource utilization	(Mourtzis,2011)
6	Increased productivity, Organizational efficiency and improved services	(Singh,2015)
7	Sustainable supply chain - Decisions based on environment	(Khan et. al., 2016)
8	Early problem detection	(Jauhari,2009)
9	Quick response	(Jauhari,2009) (Mourtzis,2011)
10	Reduced cycle time from order to delivery	(Singh,2015)

Table 1: Benefits of Information Sharing (Adapted from: Lotfi et al., 2013)

(Yan et al.,2001) have demonstrated on how cost and inventory level reduces when the information sharing between the retailer and manufacturer is gradually increased. The authors have found that there is a pareto improvement which means that all members have benefited, and some members have strongly benefited in terms of cost saving when information share level is increased in steps. (Gaur et al., 2005) have explored on how when demand has an information when shared up the stream in a two-stage supply chain model by the retailer to the manufacturer, lead to significant benefits like the safety stock reduction at the manufacturer side. This study implies that demand as information share is found to lead to substantial benefits not only to the manufacturer or retailer but also to the overall supply chain system.

2.3.1 Demand Information Sharing in Advance

This chapter has adapted partially the concept of demand information in scenario 2 of the partial information sharing system. So, reviews carried out on it are as below:

(Hariharan and Zipkin, 1995) studied the supply chain system performance when the customer demand information is received in advance. They have developed a model describing it and the output analysis from the model is that the 'demand lead time' improves the performance of the system whereas the 'supply lead time' worsens it. Their study also exposes that this early information is a substitute for supply lead time and if managed well could reduce the safety stock and its corresponding cost in the supply chain system.

(Karaesmen et al., 2013) propose that if the advance demand information is handled effectively then the production/inventory performance would gradually increase. They have derived prepositions which tell us on which scenarios the advance information received could be meaningful and generate more benefit.

2.3.2 Vendor Managed Inventory (VMI)

(Marques et al., 2010) has studied the concept of VMI from concept to process and summarizes on the operational and collaborative element in VMI. According to the authors, VMI is a supply chain integration where in the focus is on the continuous replenishment of the customers inventory. They also say that the partners share demand, requirements and constraints so they can have a shared objective.

(Yao et al., 2007) evolved a mathematical model for a single-vendor single-retailer VMI system. The demand information is assumed to be deterministic and the model carried an analysis on the cost performance between a system with VMI and a system without VMI. Results reveal that the benefits are found to be spread between the buyer and the supplier in an uneven manner. But in alignment to existing literatures, (Yao et al., 2007) found that implementation of VMI does reduce the inventory cost of the system thus rendering it to be beneficial.

2.4 Inventory Model Decisions

In a supply chain, a key aspect that establishes the health of the system is the inventory management. The financial upturn or downturn is very much determined by the inventory management decisions. It not only impacts a member in the chain, it affects in all layers. Hence maintaining an optimum value of inventory in a system supports the fiscal growth of the organization. In this thesis the decisions for an inventory model has been considered as per the Figure 4.

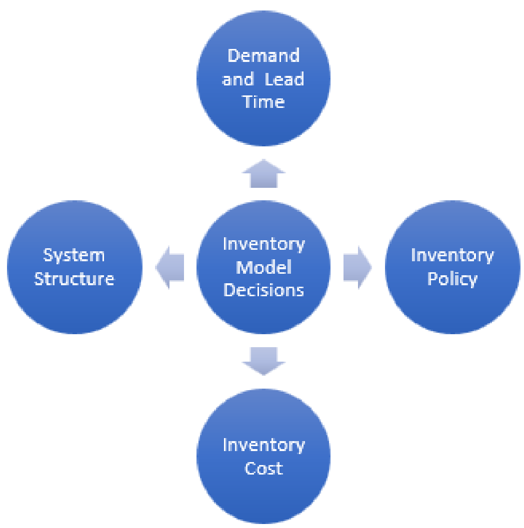


Figure 4: Inventory Model Decisions

2.4.1 System Structure

System Structure is about the distribution structure of a firm. It varies greatly from industry to industry and based on the nature of the product and the consumer demand patterns. It could be considered as a system configuration which is a key and fundamental start point to an inventory model decision. Based on the storage location of inventory in a system there is Single Stage or Multi Stage system. There could be single or multiple products as output from this system. But the total quantity produced is strongly dependent on the production capacity, cost allocations and demand received from consumers.

Arborescent System are those systems in which each inventory location is served by a single source. Two networks in it could be the Serial State Network and the Multi Level Network (Figure: 5) (Hopp and Spearman, 2011)

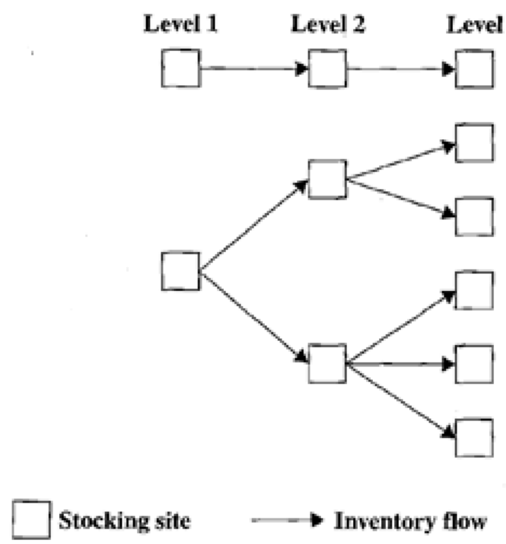


Figure 5: General Arborescent Systems (Source: Hopp and Spearman, 2011)

In the serial system there are many stocking sites in series and each site serves only one destination site. Usually supply is also from a single source. In the multilevel arborescent system, the stocking sites may supply to more than one destination and there is multi level in it.

In supply chain, the member close to the customer is said to be down the stream and the member close to the supplier is up the stream. Down the stream the demand information is understood from the consumers and produce is supplied as required to them. Upstream the procurement from the suppliers on raw material required is carried out so it can be used for manufacturing or distribution to the retailers who in turn supply to the customers. Information flow in this supply chain is always up the stream and the goods flow down the stream. Figure 6 is represented to show clearly on upstream and down stream in a two-stage network system.

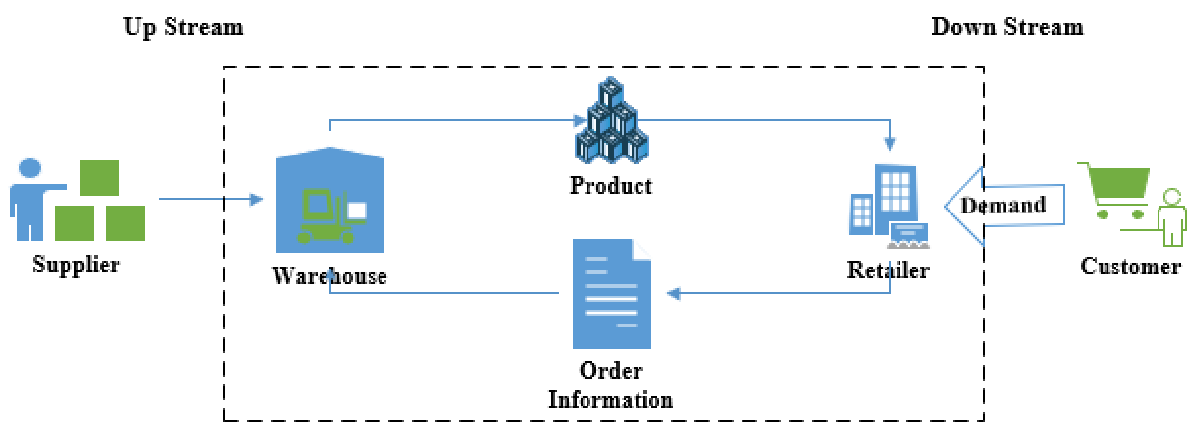


Figure 6: Arborescent Series – Two Stage System

Also, the network system that this chapter shall consider would be the series two stage system as depicted in Figure 6. The goal of the thesis is to simulate and understand the benefits when the collaboration among the members is improved gradually, so the idea is that if initially in a series system the outputs are achieved exploring it further with multi level could be progressive.

2.5 Simulation

According to (Banks et al., 2010), simulation is an approach to study systems in the conceptual phase before implementation, thus it can serve as either an analysis tool to know in advance about the impacts in incorporating changes to existing system or as a design tool to know the performances of the new design in under varying conditions.

(Kelton and Barton, 2003) have conveyed on how a carefully planned simulation could yield valuable information with any undue computational time or efforts. In the simulation context, they have shared on some ideas, challenges and opportunities when looking to model and study behaviour patterns from the simulation models.

Also, model is defined as a system's representation in order to study the system in detail, where the system is clarified to be a group of objects that work together in a known pattern of interaction or in some interdependence with each other so that a common objective is met. So, the term modelling is the process of creating this representation of the system (Banks et al., 2010).

The thesis models are generated with the view that the supply chain system could be studied so that by measuring its performance the operations could be improved and redesigned to capitalize on the benefits.

2.5.1 Simulation in Supply Chain

For many years, analytical modeling has been the tool which has been used by management for supply chain, but it was more theoretical and did not solve practical problems. In this context (Swaminathan et al., 1996) has reviewed that Simulation has gained considerable attention and momentum. The authors have also identified various purposes when using modeling and simulating a supply chain system. The result of their research evidently depicts on how analytical results could be coupled with simulation and the model by itself is able to serve as a tool for decision making to industries. (Swaminathan et al., 1996).

Managing a complex supply chain is very much necessary, so that a business can thrive successfully in today's scenario. Understanding the impact of a company's policy on the supply chain is not likely to be known before the role out of the policy. Here the supply chain simulation models facilitate to bridge this gap. Mathematical model or Analytical may have proven success in getting the results if at the system was simple but for real life complex problems studying the system via simulation would be the best. (Law and Kelton, 2000)

2.5.2 Discrete Event Simulation

As per (Rossetti, 2015), simulations could be classified from perspective of time as static or dynamic, stochastic or deterministic and discrete or continuous. The author further details, a static system to be a system which is constant over time and a dynamic system evolves over time. Also, the system if found to be random in nature then it is stochastic else it is considered as a deterministic system. From a function of time standpoint, (Rossetti, 2015) clarifies that discrete systems are those that have their state changes at discrete point in time whereas in continuous system the state changes occur continuously. He further explains that in a discrete event simulation when a specific change happens in the system, observations are collected at that point in time but in continuous event simulation the observations are collected continuously over the period. In this thesis, the focus of the discrete simulation event model would be stochastic and dynamic in nature.

Discrete Event Simulation gives the opportunity to evaluate the operating performance in advance to the implementation of the actual system. What-if analysis could be carried out by the companies which aides them in efficient decision making with such models. Also, various operational alternatives could be identified from these models without disturbing the existing systems for a better policy decision (Chang and Makatsoris, 2001). The authors have also mentioned that prior to start of the supply chain modeling one should be aware of the entire supply chain. Also identifying the correct performance measure is vital. (Chang and Makatsoris, 2001).

2.6 Why Discrete Event Simulation?

In order to understand the various methodologies used to evaluate information sharing in a supply chain, the last ten years literary work has been reviewed and summarised in table 2. Google Scholar was used to find the papers. The top results with respect to each year has been captured and reviewed.

Author	Year	Topic	Methodology
Jiang and Ke	2019	Information sharing and bullwhip effect in smart destination network system	Mathematical
Kiyoung and Jae-Dong	2019	The impact of information sharing on bullwhip effect reduction in a supply chain	Simulation
Raweewan and Ferrel	2018	Information sharing in supply chain collaboration	Other
Srivathsan and Kamath	2018	Understanding the value of upstream inventory information sharing in supply chain networks	Mathematical
Li et. al.	2018	Information and profit sharing between a buyer and a supplier: Theory and practice	Other
Dominguez et. al.	2018	OVAP: A strategy to implement partial information sharing among supply chain retailers	Simulation
Zhao et. al.	2018	What is the value of an online retailer sharing demand forecast information?	Mathematical
Ali et. al.	2017	Supply chain forecasting when information is not shared	Other
Zaheer and Trkman	2017	An information sharing theory perspective on willingness to share information in supply chains	Other
Minkyun and Sangmi	2017	The impact of supplier innovativeness, information sharing and strategic sourcing on improving supply chain agility: Global supply chain perspective	Other
Haobin et. al.	2017	Enhancement of supply chain resilience through inter-echelon information sharing	Simulation

Khan et. al.	2016	Information sharing in a sustainable supply chain	Mathematical
Wenliang et. al.	2016	Two-way information sharing under supply chain competition	Other
Pan et. al.	2016	Revisiting the Effects of Forecasting Method Selection and Information Sharing Under Volatile Demand in SCM Applications	Mathematical
Choudhary et. al.	2016	VMI versus information sharing: an analysis under static uncertainty strategy with fill rate constraints.	Mathematical
Rached et. al.	2016	Decentralized decision-making with information sharing vs. centralized decision-making in supply chains	Mathematical
Rached et. al.	2015	Assessing the value of information sharing and its impact on the performance of the various partners in supply chains	Mathematical
Salvatore et. al.	2015	A simulation model of a coordinated decentralized supply chain	Simulation
Costantino et. al.	2015	The impact of information sharing on ordering policies to improve supply chain performances	Simulation
Giloni et.al.	2014	Forecasting and information sharing in supply chains under ARMA demand	Mathematical
Cannella et. al.	2014	An IT-enabled supply chain model: a simulation study	Simulation
Cigolini et. al.	2014	Linking supply chain configuration to supply chain performance: A discrete event simulation model.	Simulation
Yan et. al.	2014	Intelligent Supply Chain Integration and Management Based on Cloud of Things	Other
Ming et. al.	2014	Demand information sharing and channel choice in a dual-channel supply chain with multiple retailers	Mathematical
Inderfurth et. al.	2013	The Impact of Information Sharing on Supply Chain Performance under Asymmetric Information	Other
Fei and Zhiqiang	2013	Effects of information technology alignment and information sharing on supply chain operational performance.	Other
Jin Kyung Kwak	2013	Comparison of (s, S) and (R, T) Policies in a Serial Supply Chain with Information Sharing	Mathematical
Lin and Shayo	2012	Systems Dynamics Modeling for Collaboration and Information Sharing on Supply Chain Performance and Value Creation	Simulation
Yang Feng	2012	System Dynamics Modeling for Supply Chain Information Sharing	Simulation
Mourtzis	2011	Internet based collaboration in the manufacturing supply chain	Other

Taho et.Al.	2011	Evaluation of robustness of supply chain information-sharing strategies using a hybrid Taguchi and multiple criteria decision-making method	Other
Saxena et. al.	2010	Simulation-based decision-making scenarios in dynamic supply chain	Simulation
Prakash and Deshmukh	2010	Horizontal Collaboration in Flexible Supply Chains: A Simulation Study	Simulation
Bottani and Montanari	2010	Supply chain design and cost analysis through simulation.	Simulation
Yu et. al.	2010	Evaluating the cross-efficiency of information sharing in supply chains	Simulation
Mei et. al.	2010	Supply chain collaboration: conceptualization and instrument development	Other
Li and Hau	2009	Information Sharing and Order Variability Control Under a Generalized Demand Model	Mathematical
Jain et. al.	2009	Enhancing flexibility in supply chains: Modelling random demands and non-stationary supply information	Mathematical
Chan and Chan	2009	Effect of information sharing in supply chains with flexibility	Simulation
Saxena et. al.	2009	Flexible configuration for seamless supply chains: Directions towards decision knowledge sharing	Simulation

Table 2:Literature Work - IS Methodologies

The literary work has then been categorized per the research methodology. Table 3 shows the results distribution. It can be seen that simulation scores the highest followed by mathematical optimization models and others which includes approaches like game theory, theoretical framework, survey-based framework etc.

IS Methodologies	Nos	% of paper
Simulation (discrete event simulation or system dynamics)	15	38%
Mathematical Programming	13	33%
Other – (Survey, Qualitative, Literature Review)	12	30%
Tota l	**40**	**100%**

Table 3:Literature Work - IS Methodologies - Summary

Figure 7 gives a graphical representation for a better understanding. Compared to all other methodologies' simulation is found to be more adaptive and suitable for this objective compared to other approaches. Hence, discrete event simulation has been adopted in this thesis.

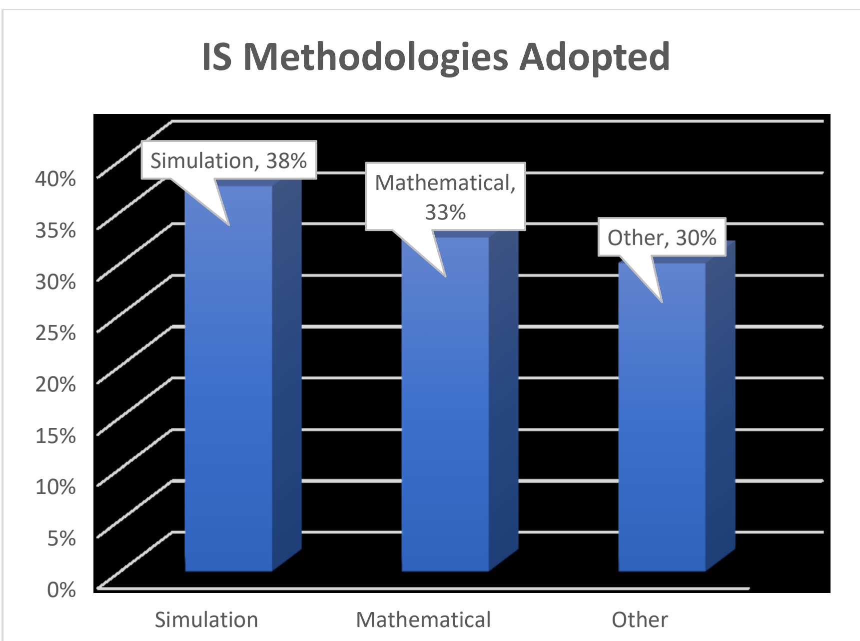


Figure 7: Literature Work - IS Methodologies -Graph

CHAPTER 3:

SOLUTION APPROACH

3.1 Simulations Steps

Simulation is not only about replicating a real-world scenario, it is also the best representation of the system and their complex interrelationships as a function of time (Rossetti, 2015). The idea is that the required future system is achieved by a flexible model of the real physical system, coupled with its correlated elements, modelled and validated with various scenarios until the predicted system is obtained. The process flow shown in Figure 8 is adopted to meet the problem's objective.

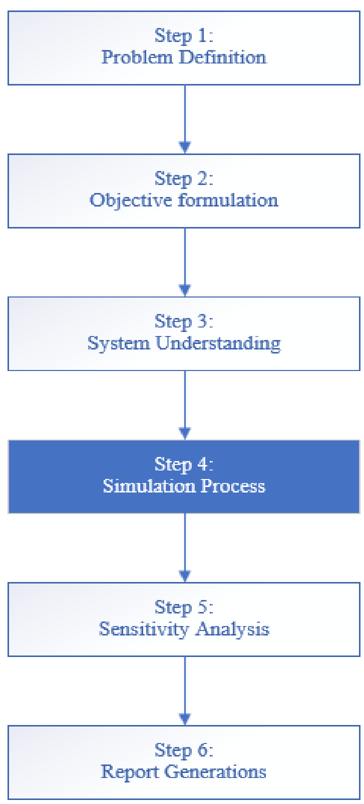


Figure 8: Solution Approach

In order to simulate, the foremost step is to understand the problem and identify the scope. In this chapter, sections 1.2 and section 1.3 explain these steps 1 and 2 of the simulation process. Step 3 is dedicated to system understanding, and formulating the model decisions which support in ensuring that the simulation model is able to address the problem for a system considered. Section 3.1 and section 3.2 gives a more elaborate description with respect to the decisions, assumptions etc. Step 4 is the simulation process. This is an iterative process which is further clarified in Figure. 9. The flow defines on how the model is developed. It comprises of four stages: Model Conceptualization, Numerical Analysis, Model Implementation and Model Execution.

Model Conceptualization

Before the model implementation, a UML design is formulated with the system definitions set with respect to the inputs and outputs that require to be considered. A case diagram is first formulated to understand on the flow between the supply chain members namely consumers, retailers, and warehouse. By drawing the case diagrams, the activity flow in the system is clarified and this is reviewed against the essentials that are necessary towards the defined problem. Section 3.2 describes the representation of the flow with respect to the three scenarios under discussion.

Numerical Analysis

To evaluate the conceptualized model theoretically, a numerical analysis is carried out. An excel based macro sheet (Rossetti, 2015) has been adapted and updated to be used for various set of values to understand on the total cost of the supply chain with respect to the three levels of considered collaboration. Three excel spreadsheets are implemented based on the three level scenarios and mathematically the values are generated so that the model results could be validated according to it. Appendix A gives the view of the three spread sheet which has the mathematical evolution carried out before the model execution.

Model Implementation

With the model concept and the numerical analysis sheet, the adaption of the real system to the Arena simulation model is carried out. The level of detailing is ensured to be as close to the concept planned and for the inputs as designed from the numerical analysis sheet. Before the model is implemented in the Arena, the variables, attributes, events and queues are first identified with respect to both the retailer and the warehouse side. These parameters are derived based on the logic that is required to be modeled as detailed in the model conceptualization phase.

Model Execution

The developed model is then run for various demand values to understand on total cost with respect to the collaboration. The model goes through the verification and validation process.

Model Verification

This process is to ensure that the model is complete in all intended aspects and the outputs generated from it is close to the results generated from the numerical analysis sheet. The two main steps followed in this process are the setting up of the initial values and then observing the output for any variations. The main objective of this step would be that if the inputs are set as required then whether the logical structure planned is well represented by the model. This is evaluated from the statistical outputs generated by the model which aids in verifying the model. The input controls are then varied in such a way that all scenarios are covered, also the best and worst scenarios are passed.

Model Validation

This process is carried out to ensure closeness of the model to the real system. In the model validation phase, a Sensitivity Analysis of the system is carried out. The retail world is considered here, hence the parameters and entity set are brought close to the retail environment. The respective controls are identified, and these are varied and the outputs from it are observed. Many trials are executed via the process analyzer tool and the output is studied in relation to the actual system under discussion.

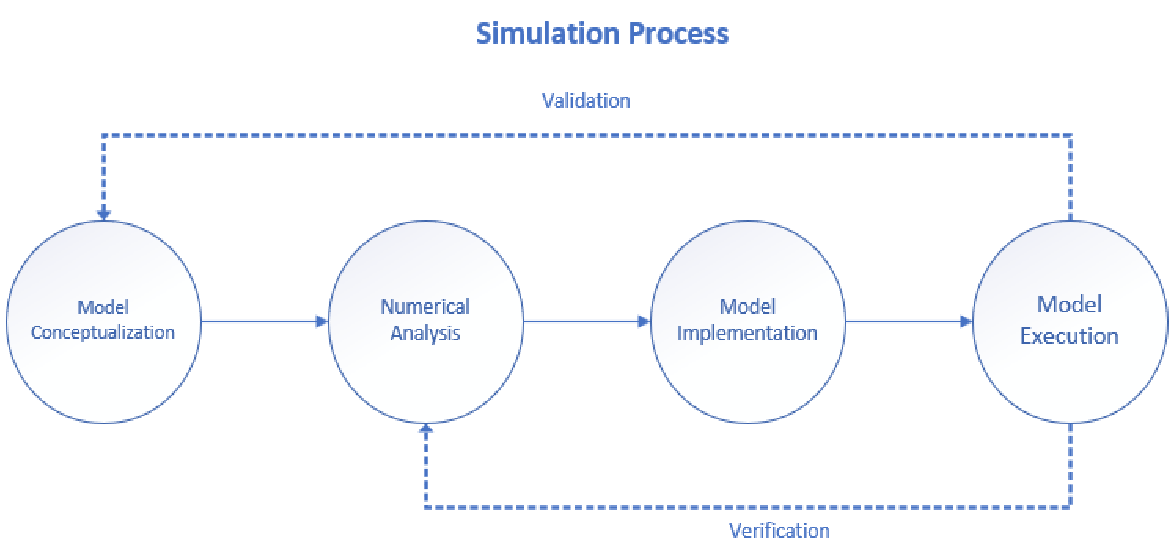


Figure 9: Simulation Process

3.2 Inventory Level and Cost Calculations

The below notation shall be considered to understand the various cost calculations in the supply chain. Sections 2.4.3, 2.4.4 and 2.4.5 shall be referring to these notations

D – Demand rate per year

LT – Replenishment lead time in days

θ – Poisson distributed Mean demand during replenishment lead time

p(x) – Probability mass function

$$p(x) = \frac{\theta^x e^{-\theta}}{x!} \quad x = 0,1,2\ldots$$

G(x) – Cumulative distribution function

$$G(x) = \sum_{i=0}^{x} p(i) \quad x = 0,1,2\ldots$$

Q – Reorder Quantity (in units)

r – Reorder Level (in units)

h – Annual holding cost ($)

b – Annual backorder cost ($)

o – Annual ordering cost ($)

I(r) – Average inventory on hand with respect to the reorder level r (in units)

IN(r) – Net inventory on hand (in units)

B(r) - Average back order with respect to the reorder level r (in units)

F(Q,r) – Order frequency with respect to Q and r (in units)

S(Q,r) – Fill rate with respect to Q and r (in units)

B(Q,r) – Average backorder number (in units) with respect to Q and r (in units)

I(Q,r) – Average On-Hand Inventory (in units) with respect to Q and r (in units)

3.2.1 Demand rate and Lead Time

In inventory management, the two main sources from where uncertainty arises is from the demand rate and the lead time. They are also a key factor in the decision-making process towards which type of inventory policy to consider.

Demand rate could be deterministic or stochastic. Deterministic demand is known in advance and it is certain on what would be the quantity or when it would arrive.

Lead time is the time interval between the placement of order and receipt of the placed order by the customer. Again, lead time here could be constant or varied. Usually lead time has a strong dependence on the supplier.

Demand could follow many different types of distributions but two of the most important distributions available are the (discrete) Poisson Distribution and the (continuous) Normal Distribution. In Poisson distribution the mean time between the arrival rate λ is exponentially distributed, so the exponential distribution is $f(x) = \lambda e^{-\lambda t}$ $\lambda >= 0$.

Also, $\theta = \frac{\lambda LT}{365}$ which is the expected demand during the lead time.

Probability mass function

$$g(x;t) = \frac{\theta^x e^{-\theta}}{x!} \quad x = 0,1,2\ldots \tag{1}$$

Cumulative distribution function

$$G(x;t) = \sum_{i=0}^{x} g(x;t) \quad x = 0,1,2\ldots \tag{2}$$

The frameworks in this chapter consider a stochastic discrete demand which follows a Poisson Distribution and a fixed lead time.

Inventory Theory base formula:

(Zipkin, 2000) has analyzed the (r,Q) inventory model and has resulted in base equations when the demand rate is in a Poisson distribution. The analytical inventory formulas as provided by (Zipkin, 2000) are as below:

Poisson complementary cumulative distribution function:

$$G^0(x;t) = 1 - G(x;t) \tag{3}$$

Poisson first-order loss function:

$$G^1(x;t) = -(x - \lambda t)\, G^0(x;t) + (\lambda t)\, g(x;t) \tag{4}$$

Poisson second-order loss function:

$$G^2(x;t) = (1/2)\ \{[(x - \lambda t)^2 + x]\, G^0(x;t) - (\lambda t)\,(x - \lambda t)\, g(x;t)\} \tag{5}$$

3.2.2 Inventory Policy

With the demand being uncertain and random, there are two significant models which could be suited. If in a scenario, random demand occurs the model in which inventory is replenished one unit at a time, then the only issue is to determine the reorder point. The target inventory level set for the system is known as a base stock level, and hence the resulting model is termed the **base stock model** (Hopp and Spearman, 2011). The model in which the demand occurs randomly, possibly in batches, then here the inventory is monitored continuously. As per (Hopp and Spearman, 2011) when the inventory level reaches (or goes below) r, an order of size Q is placed. After a lead time of l, during which a stockout might occur, the order is received. The problem is to determine appropriate values of Q and r. The model we use to address this problem is known as the **(Q, r) model** (Hopp and Spearman, 2011). This thesis shall deal more with the (Q,r) model as the policy considered by the retailer and the warehouse follows this policy for satisfying the demand received from the customer.

(Q, r) inventory control policy:

This inventory policy is a continuous review with backordering involved in it. The customer order information keeps coming in one at a time in some stochastic manner. To meet the demand as it arrives the order request is checked against the current stock availability in the system. If it is available, the customer order is relinquished immediately, and the stock availability is decreased by a count. But if stock is not available then the customer order is backordered in a queue which acts on a first come first serve basis. The inventory position is checked every time when ever an order is met or backordered against the reorder point r to decided whether an order needs to be placed. If the inventory position goes below the reorder level r, then a re-order quantity of Q units is placed. This Q units ordered comes after a fixed time, which is the lead time LT from the supplier. After this time once the order is received the customer order as well the backorder as per the queue is met.

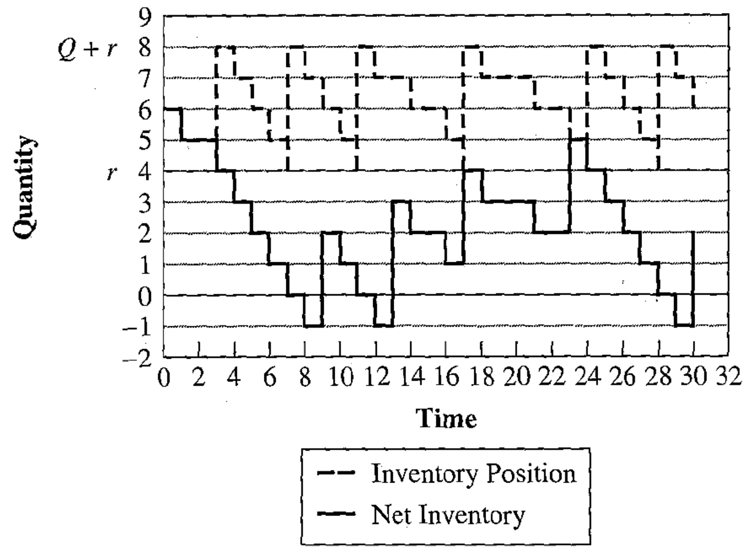


Figure 10: (Q,r) inventory model with Q=4 and r=4 (Source: Hopp and Spearman, 2011)

In this concept, there are three main inventory levels and a service rate to understand on. These terminologies are explained as follows

Net Inventory:

This is the inventory on hand or the available stock at a unit of time without considering on the backorder. This inventory keeps decrementing every time a customer order is met and increments whenever a requested order is received. The net inventory is therefore understood as below:

Net Inventory = inventory on hand – backorder level

Inventory Position:

This represents the level of net inventory along with inventory in order. On a inventory level it is the actual position at that instant. It is represented as:

Inventory Position = inventory on hand – backorder + inventory on order

Since it has all the required inventory level interlinked, it becomes the ideal parameter to check against the reorder level to take a decision on whether to reorder or not.

Backorder Level:

It is the number of units which are backordered as the inventory on hand is not available. It keeps incrementing till the order placed is replenished. It has an associated cost which is charged per unit time till it gets to serve the cost who is waiting on his backordered unit.

Fill rate:

The term fill rate is associated to the stock out condition of the inventory. Stock out represents the duration of time that the system is in the out of stock situation. It is represented in terms of percentage and ideally the lesser the percentage the better is the performance of the system. Fill rate is just 1 minus of the stock out rate. It is the duration for which there is inventory on hand to serve the customer.

Fill rate - 1 – stock out

The average fill rate, backorder level and the inventory level in terms of Q and r has been deduced by (Zipkin, 2000) and it is given as below:

S(Q,r) – Fill rate with respect to Q and r (in units)

$$\overline{SO} = \frac{1}{Q} [G^1(r ; L) - G^1(r+Q ; L)] \quad (6)$$

B(Q,r) – Average backorder number (in units) with respect to Q and r (in units)

$$\overline{B} = \frac{1}{Q} [G^2(r ; L) - G^2(r+Q ; L)] \quad (7)$$

I(Q,r) – Average On-Hand Inventory (in units) with respect to Q and r (in units)

$$\overline{I} = (1/2)(Q+1) + r - \lambda L + \overline{B} \quad (8)$$

Based on (Zipkin, 2000) equations from (3) to (8), (Hopp and Spearman, 2011) derived the equations for the fill rate, average backorder level and on-hand inventory in terms of the backorder. These equations aid in bringing up an excel based inventory analysis sheet which has been extensively used in the numerical evaluation of the model. The base of the excel has been considered from (Rossetti, 2015) but the formula clarifications are discussed in this section.

S(Q,r) – Fill rate with respect to Q and r (in units)

$$S(Q, r) = 1 - \frac{1}{Q}[B(r) - B(r + Q)] \quad (9)$$

B(Q,r) – Average backorder number (in units) with respect to Q and r (in units)

$$B(Q, r) = \frac{1}{Q}\sum_{r+1}^{r+Q} B(r) \quad (10)$$

I(Q,r) – Average On-Hand Inventory (in units) with respect to Q and r (in units)

$$I(Q, r) = \frac{Q+1}{2} + r - \theta + B(Q, r) \quad (11)$$

3.2.3 Inventory Costs

Some of the financial parameters dealt in the thesis in order demonstrate on the total cost reduction is as described below:

Ordering Cost or Fixed Setup Cost (OC):

This cost is also referred as the replenishment cost and this cost is incurred every time an order is placed. It is the product of number of replenishment /Order Frequency carried out in a year and the replenishment cost factor associated to it. The order frequency as per (Hopp and Spearman,

2011) is the number of orders carried out over a period. In thesis the period of consideration is for a year. Hence the order frequency and the associated ordering cost is as per equation given below by the authors

Order Frequency F (Q, r) = $\frac{D}{Q}$ (12)

Ordering Cost (OC) = F(Q,r) * o (13)

Holding Cost (HC):

All the cost that goes into storing of the inventory at a storage location is called the holding cost. It is usually the product of the actual inventory level held and the holding cost factor.

Holding Cost (HC) = I (Q, r) * h (14)

Backorder Cost (BC):

The cost that is incurred every time when ever a customer order is not satisfied is called the Backorder Cost. It is the product of the backorder inventory level and the cost factor associated with the backorder. This cost factor in fact is a penalizing fee on not satisfying the requested customer demand.

Backorder Cost (BC) = B (Q, r) * b (15)

Total Cost (TC):

The sum of all the above costs is the total cost. The total cost of the supply chain needs to be at the minimum so that profit could be improved. The information sharing model considers this total cost to be the performance measure component to understand on how the level of collaboration improves on the reduction of this total cost. This cost considers the ordering cost, holding cost and the backorder cost and its equation is given as below:

Total Cost (TC) = OC + HC + BC (16)

3.2.4 Sample (r,Q) Inventory policy Calculation

In order to summarize on the equation's usage in this thesis, a sample numerical calculation is demonstrated below. This explains on the excel spreadsheets numerical values got for an input control parameter.

Say the annual demand poisson rate D = 50, Lead Time LT = 45 days and the Optimum Controls are Q = 7 and r = 8. Also, for a cost say h = 30$, b = 100$ and 0 = 15$

For equations (9) to (11) the value of p(R), G(r) and B(r) is required, from the excel macros we understand these values and they are as represented in table 4 which represents the fill rate for values of the reorder point.

Continuous review (r, Q) Policy with backordering
Poisson Demand

D	LTw	θw
50	45	6.1644

R	p(R)	G (R)	B (R)
8	0.109	0.830	0.358
9	0.074	0.904	0.188
10	0.046	0.950	0.092
11	0.026	0.976	0.042
12	0.013	0.989	0.018
13	0.006	0.995	0.007
14	0.003	0.998	0.003
15	0.001	0.999	0.001
16	0.000	1.000	0.000
17	0.000	1.000	0.000
18	0.000	1.000	0.000

Table 4: Fill rate for respective R values

So, calculation of the fill rate, Backorder level, Inventory on hand and Order frequency with respect to the function of Q and r are as explained below:

$S(Q, r) = 1 - \frac{1}{Q}[B(r) - B(r + Q)] = 1 - \frac{1}{7}[B(8) - B(15)] = 0.949$

$B(Q, r) = \frac{1}{Q}\sum_{r+1}^{r+Q} B(r) = \frac{1}{7}\sum_{r=9}^{r=15} B(r) = 0.0502$

$I(Q, r) = \frac{Q+1}{2} + r - \theta + B(Q, r) = \frac{7+1}{2} + 8 - 6.1644 + 0.050 = 5.886$

$F(Q, r) = \frac{D}{Q} = \frac{50}{7} = 7.143$

Ordering Cost (OC) = F(Q,r) * o = 7.143 * 15 = 107.145 $

Holding Cost (HC) = I (Q, r) * h = 5.886 * 30 = 176.576 $

Backorder Cost (BC) = B (Q, r) * b = 0.0502 *100 = 5.02 $

Total Cost (TC) = OC + HC + BC = 107.145 + 176.576 $ + 5.02 = 288.741 $

The above calculated inventory levels and costs when compared with the calculations in the excel macros are to be the same. Figure 11 shows the value as seen in the excel spreadsheet which is used by the thesis for the information sharing model.

D	θw	Rw	Qw	SO	Fill Rate	I	B	OF	HC	BC	OC	TC
5	0.616438	1	2	0.076	0.924	1.900	0.017	2.500	57.004	1.657	37.500	96.161
20	2.465753	5	4	0.014	0.986	5.041	0.006	5.000	151.218	0.637	75.000	226.855
50	6.164384	8	7	0.051	0.949	5.886	0.050	7.143	176.576	5.024	107.143	288.743
220	27.12329	31	15	0.048	0.952	11.988	0.111	14.667	359.625	11.080	220.000	590.705

Figure 11: Inventory level and Cost Calculation Example.

3.3 Supply Chain Collaboration - Model Conceptualization

Three simulation models are developed as per the information level sharing. The models developed align as per the below key assumptions:

- The retailer and warehouse, each follow the continuous (r,Q) policy

- The demand follows the Poisson Distribution process
- Demand that is not met is backordered
- Replenishment lead time is fixed

According to the levels of information sharing, the partnership collaboration for the three scenarios are as explained below:

3.3.1 No Information Sharing (NIS)

In this case, there is no information sharing between the retailer and the warehouse and order coordination is missing as well. Both the supply members work independently in a more 'decentralized' manner. This system is more aligned to the traditional supply chain system and the decision making on demand is found to be self reliant. Figure 12 depicts the No Information case. Here, the customer demand arrives to the retailer and based on this information and his on-hand availability of the stock the retailer raises order information to the warehouse. The warehouse similarly based on his available stocks, immediately responds to serve the retailer or raises purchase request with his suppliers, replenishes his stock and then further replenishes the supplier's inventory. Figure 12 depicts the flow in which the simulation model is developed. A two-stage network system which includes the retailer and warehouse internally and the customer or supplier at the external end is considered.

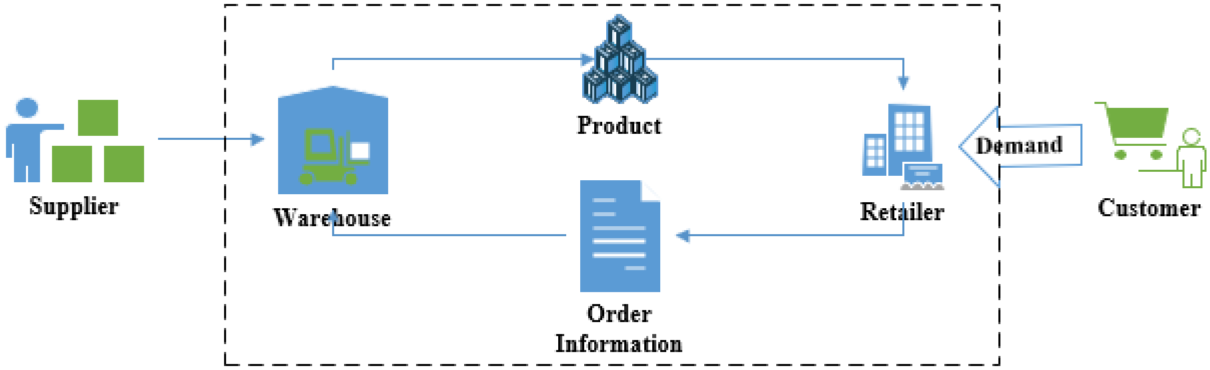


Figure 12: No Information Sharing (NIS)

The detailed flow of the concept is as per Figure 13. The concept is evolved from the model developed by (Tee & Rossetti, 2003). The authors have considered a warehouse and n retailers in a two-echelon inventory system and simulated it to study the effectiveness of simulation models. Their order flow is as shown in Figure 13. The authors have considered n retailers and the demand processing is as per the compound Poisson demand. The concept of the two-level system is adapted from this work but the thesis is limited to a single retailer and warehouse and hence a poisson demand rate.

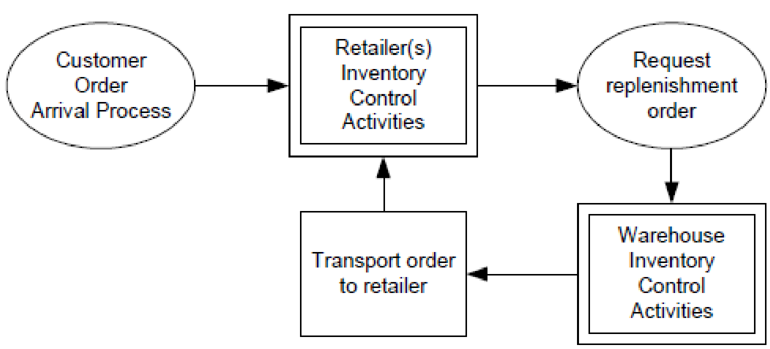


Figure 13: Order flow in two-stage system (Source: Tee & Rossetti, 2003)

Figure 13 shows the swim lane diagram to explain on the order flow between the customer, retailer and the warehouse. As the flow indicates, the customer first arrives and places his order. On this request arrival at the retailer side, the retailer processes it as per the (r,Q) policy. If retailer finds that the available inventory is not sufficient, he raises an order with the warehouse. If not, retailer would satisfy the request raised by the customer. The warehouse waits for order request from the retailer and similar to the retailer operates on the (r,Q) policy and replenishes the retailer with either inventory on hand or by replenishment from the supplier.

The performance level of the total cost of both the retailer and warehouse is considered as the prime entity for the information sharing purpose. As seen, there is no coordination here, because as the order arrives the retailer and warehouse work independently with respect to their inventory and serve the upper levels. The fill/service rate of the retailer is more significant as it is the lowest level in the system and it needs to be the highest level.

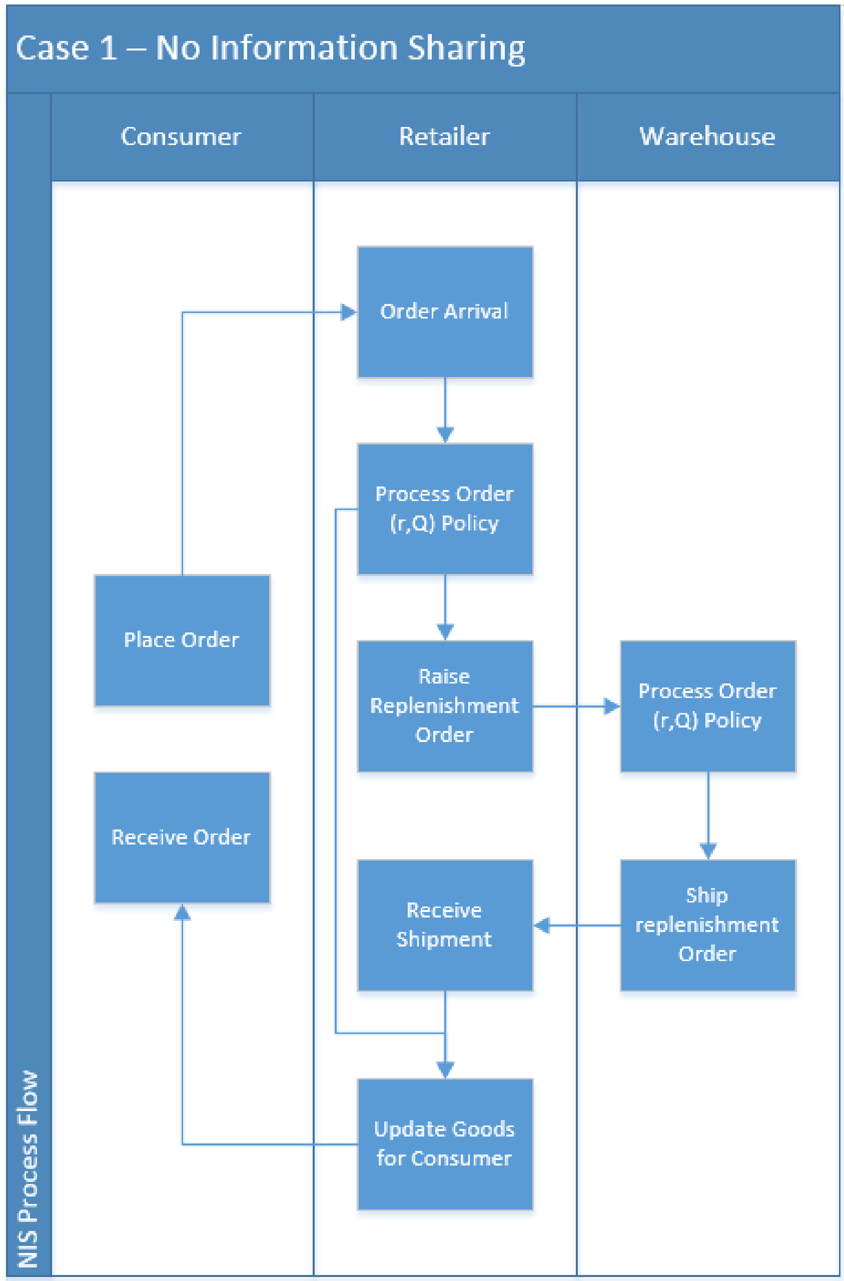


Figure 14: No Information Sharing (NIS) – Swimlane Diagram

(Hopp and Spearman, 2011) have described on how to approach a two-stage system which has a retailer and warehouse operating in continuous inventory policy with constant lead time. This concept has also been adapted in the model. According to the authors the first step would be to place the retailer re-order level and order quantity to 1 so that the warehouse receives the same poisson demand rate as the retailer. This enables us to analyze the warehouse as a single level and fix its optimum values. The backorder level of the warehouse is also known from this analysis. The author describes that the next step is finding the retailers lead time based on the warehouse delivery which is computed by the equation (17) and (18). These equations are provided by (Hopp and Spearman, 2011) and equation (17) is the wait time of an order at the warehouse and equation (18) mean effective lead time at the retailer. In the thesis, the delivery/transport time is kept constant at 1 day.

$$W = \frac{365 * B\ (Q.r)}{D} \tag{17}$$

$$E[L] = \text{Delivery time} + W \tag{18}$$

3.3.2 Partial Information Sharing (PIS)

In this case the system is to a certain extent coordinated between the retailer and warehouse. In this level the customer in advance informs the retailer that he would be placing order at a particular duration and also informs on the demand that would be placed and the due date on when he requires it. This information is shared by the retailer to the warehouse and the warehouse also keeps his supplier informed accordingly in order to meet the demand which is expected to arrive. Owing to a certain level of collaboration, the retailer and the warehouse is aware of the information in advance, they get the benefit to plan ahead and ensure to meet the customer demand. This basically leads to the reduction of the lead time which ultimately results in the backorder reduction which translates to cost savings in terms of the total operational costs of the system and profit gain. Figure 15 gives us a representation of the information and material flow in the partial information system.

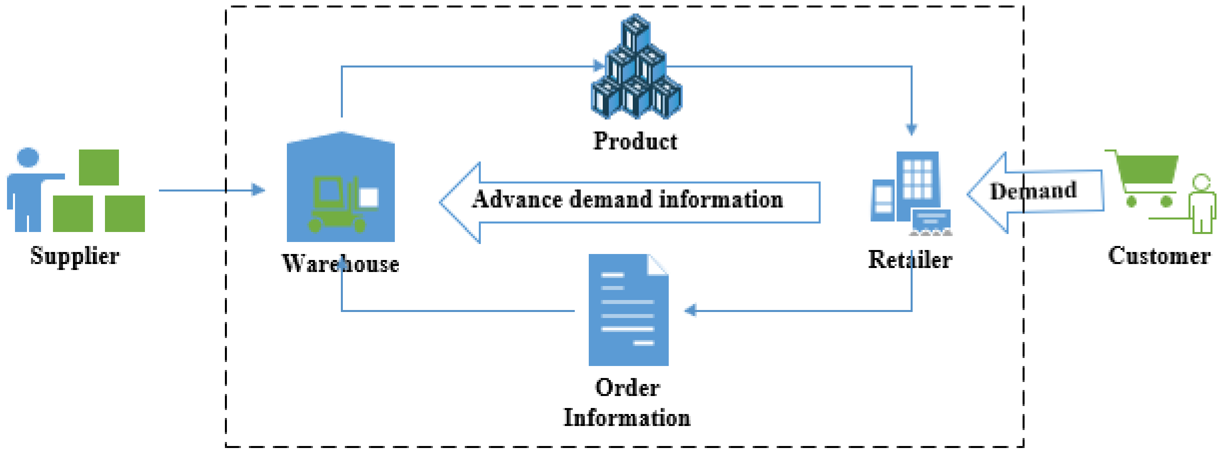


Figure 15: Partial Information Sharing (PIS)

The PIS system follows the concept explained by (Hariharan & Zipkin, 1995) on processing advance information from customer. The authors have analyzed the benefit of the ADI concept which is about knowing in advance on when a customer would arrive and after what time the customer expect to receive the order. Also, the customers will not receive the order in advance. It needs to be as per the due date set by them. From a conventional system point of view the demand lead time is the time at which the demand/order is placed by the customer. The authors have found that when the supply lead time deteriorates the performance of a system, parameter like the demand lead time elevates it.

From this concept the partial information logic is designed and it is explained in two cases as shown in Figure 16 and Figure 17. Say, Ls is the supply lead time and L_D the demand lead time, then there could be two main scenarios. In both scenarios, the customer and the retailer have advance discussion on the order requests. For the early information discussion, the customer brings information on the order quantity and on when he expects the order. The retailer brings his information on the supplier lead time to the discussion.

Case 0: When order delivery time > Ls. In this case the system has no issues and it can work as normal system, and have the order request processed in time and serve the customer on his expected due date. This is an ideal case which rarely occurs. Here the retailer based on the advance information received he could delay the order to his supplier so that the supply lead time aligns to the deliver date of the customer

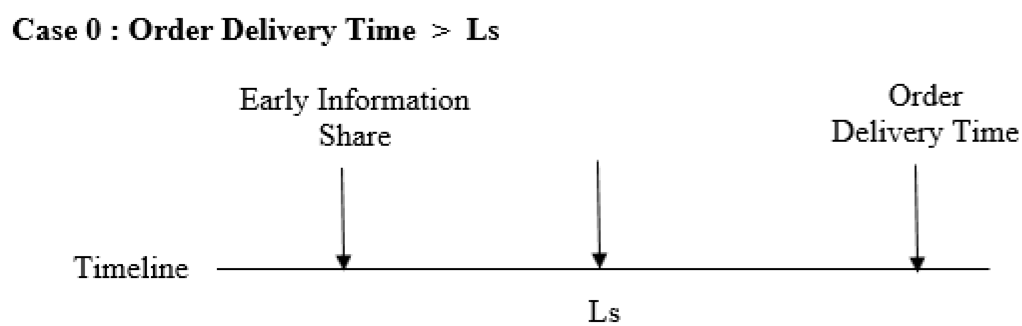


Figure 16 : Case 0: Order delivery time > Ls

Case 1: When the order delivery time is a value between and 0 and supply lead time Ls. This is a case where the supply lead time may need to be brought forward with the advance arrival information from the customer. So, if a system is aware of L_D and Ls then the supply lead time is solved by the authors as L = $Ls - L_D$. Here, when the advance info is discussed based on the Ls and order deliver time required by the customer the order arrival from the customer is planned by both the parties. Thus, with preparedness this new lead time information is considered in the system, although it is lesser than the initial value.

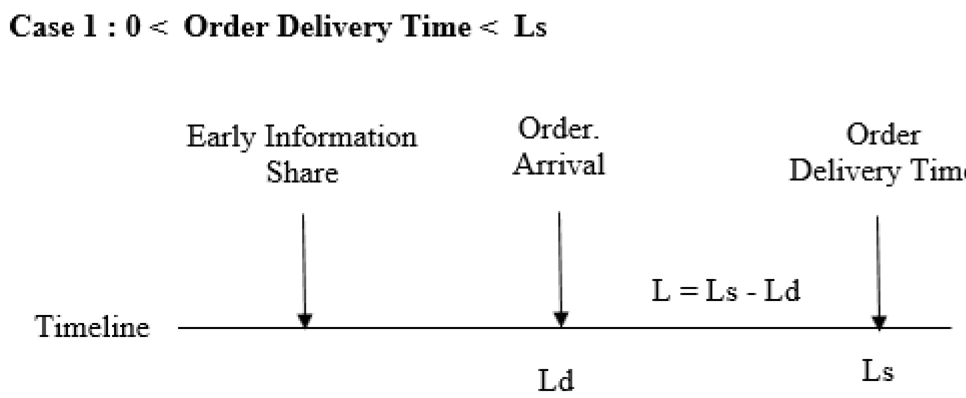


Figure 17 : Case 1: 0 < Order Delivery Time < Ls

The PIS system has adapted this concept and has model aligned to it. The reduction in lead time has eventually resulted in backorder reduction which has improved the performance of the total cost.

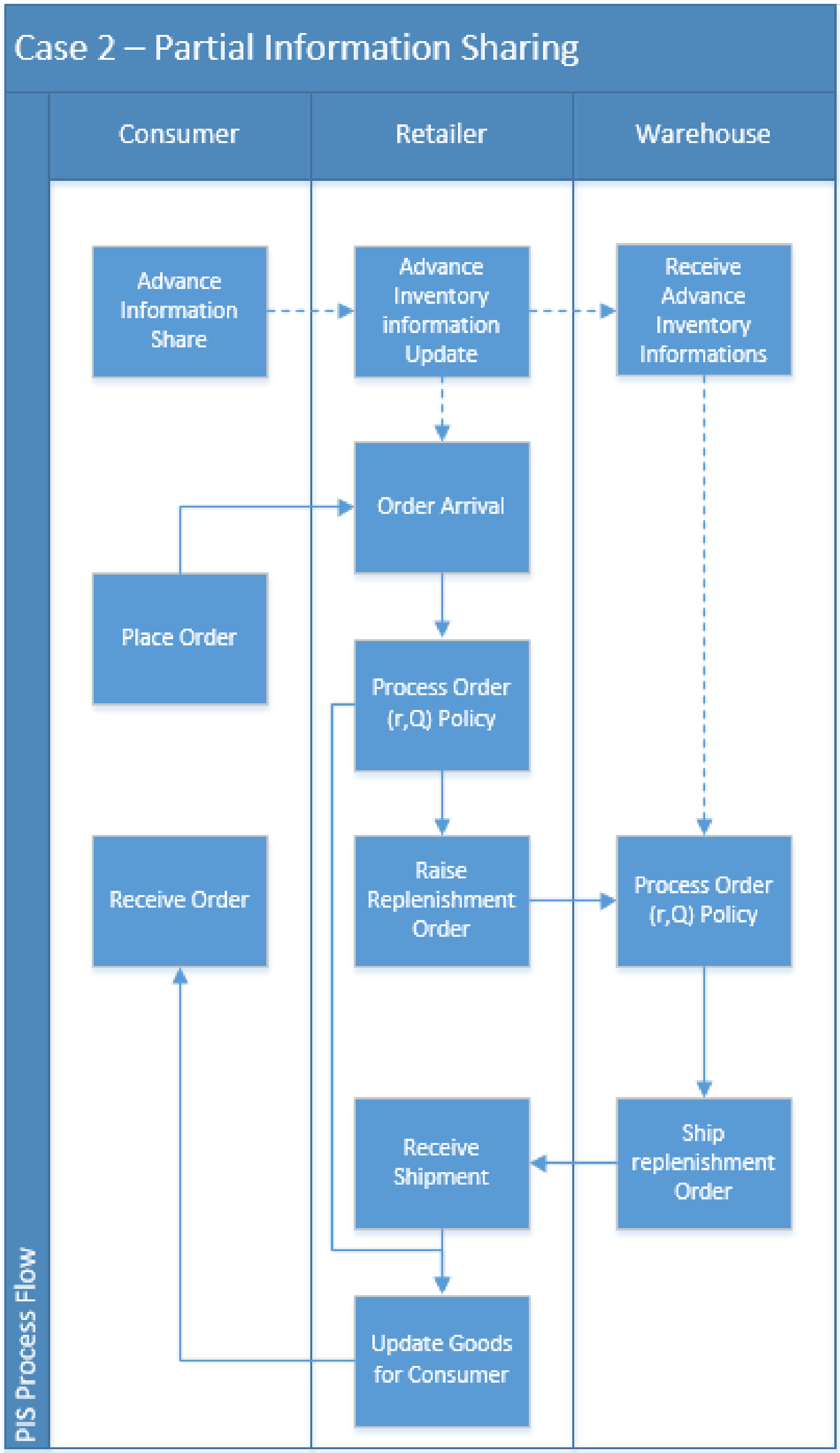


Figure 18 : Partial Information Sharing (PIS) - Swimlane Diagram

3.3.3 Full Information Sharing (FIS)

In this case, the two-stage inventory system reduces to a single stage inventory system. The retailer does not hold any inventory and transfers all demand processing information to the warehouse. As depicted in Figure 19, the retailer gets the demand from the customer and making use of the technology at hand, it updates immediately on the inventory information's to it. EDI (Electronic Data Exchange comes to play here. The warehouse similarly pulls up the information process's the request and supplies the product back to the retailer which is to be directly served to the customer. This is a Full information Sharing concept adapted from the Vendor Managed Inventory system, where in the vendor takes full control of the demand information.

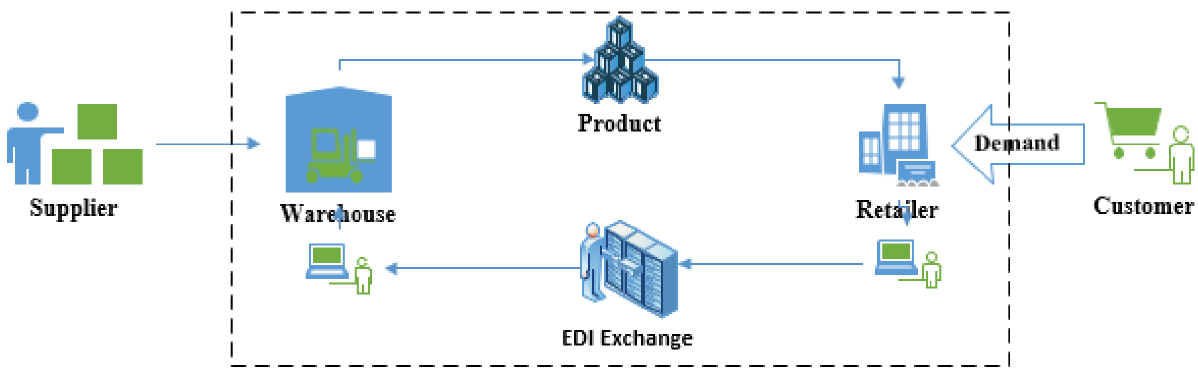


Figure 19 : Full Information Sharing (FIS)

As shown in Figure 20 the retailer publishes the inventory data received from the customer and the warehouse pulls the necessary information required for its processing and process the order and provides the information back to the retailer who in turn supplies the customer. As the upstream members take control of the inventory processing it is more a VMI aligned model.

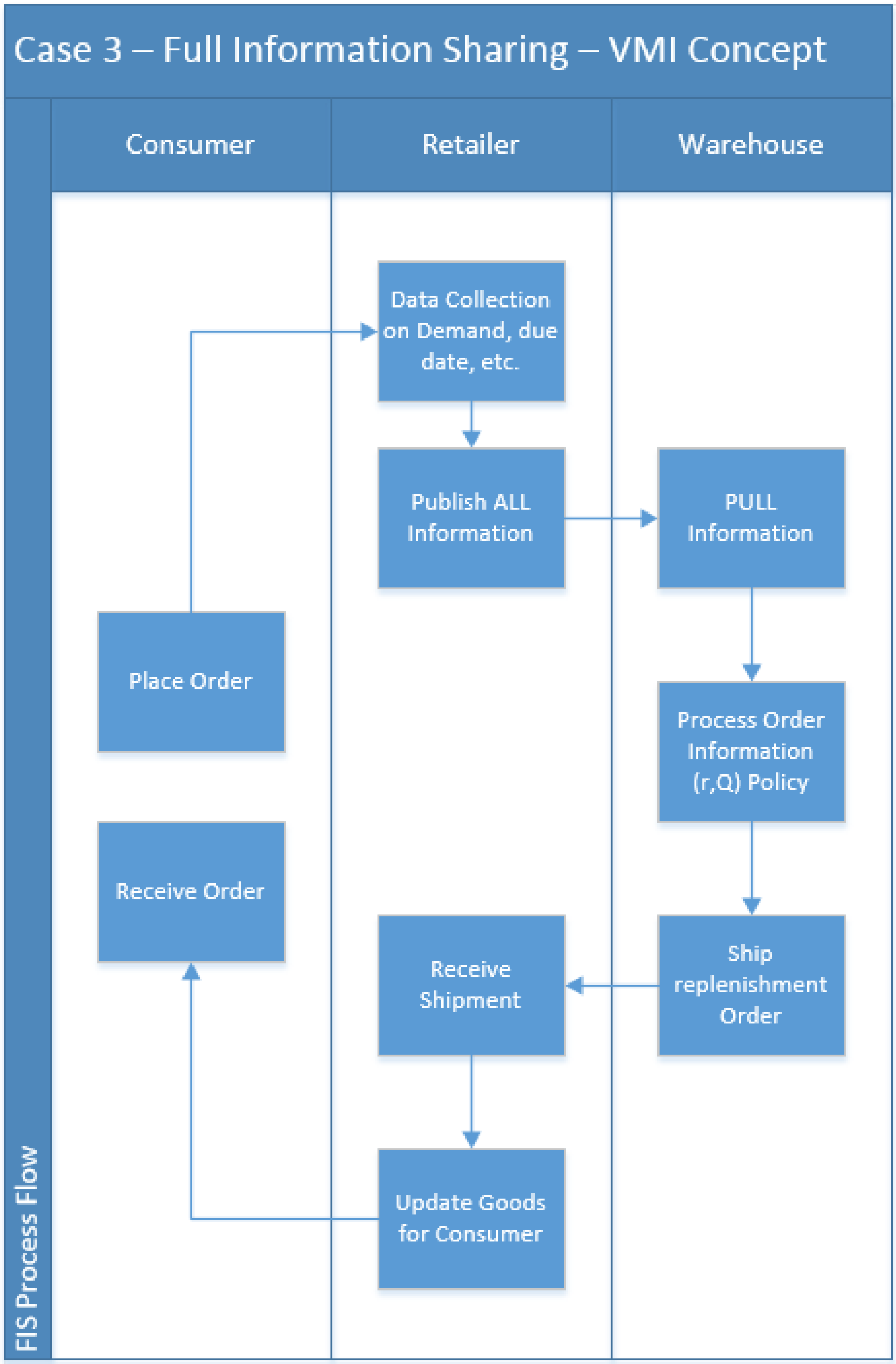


Figure 20 : Full Information Sharing (FIS) - Swimlane Diagram

CHAPTER 4:

DES MODEL TRANSLATION IN ARENA

The concepts detailed in the previous chapter are translated into the Arena models for execution. The DES elements are discussed and then the base simulation concept of the (r, Q) inventory policy for information sharing is explained further on to its translation to Arena model. Figure 21 presents the Arena and the Process Analyzer tool associated with the thesis. Any figure or discussion with respect to the Arena tool in this document will be as per this version and revision.

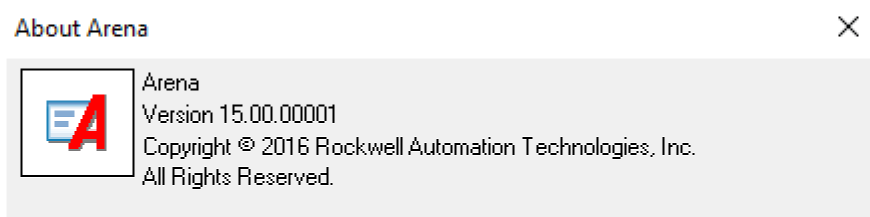


Figure 21 : Arena Version 15.00.00001

4.1 Elements of the Simulation Model

Computer simulation is found to be very beneficial in simulating the mathematical model. It could be executed many times to check the model reliability. The visualization which comes with it gives the additional advantage. Arena is a software for discrete event simulation based on SIMAN processing language. The thesis uses Arena to run experiments on a test supply chain system. It has many terminologies which define the behaviour of the system being modelled, the system description is clarified below followed by its components to support in better understanding and analysis of the system. Also, terms which are part of the Arena software are detailed for more clarity.

4.1.1 System:

It is a set of objects grouped together for some interactions or interdependent coordination between them so that a common objective is achieved by these objects in unison together. In order to model a system, it is critical to understand the concepts behind a system and on the system boundary. The system includes components such as the entities, variables and attributes which work towards the objective being set. For the current issues, the system under discussion is the two stage supply chain system working as per the inventory policy (r,Q). Some of the notable components of the supply chain system would be the retailer and warehouse and their processing of the order which gets raised by the consumer.

4.1.1.1 New Simulation Creation

Following are the steps followed to create a new project in the Arena Software

- In the Arena Software clicking on the main menu 'File' and then 'New' would be generating a new Simulation Model.
- Once a new simulation page is available, clicking on 'Run' and 'Setup' under it leads us to the Project Parameter page where the project title and other options as Figure is provided.
- The required statistics that needs to be collected are required to be chosen in this tab.

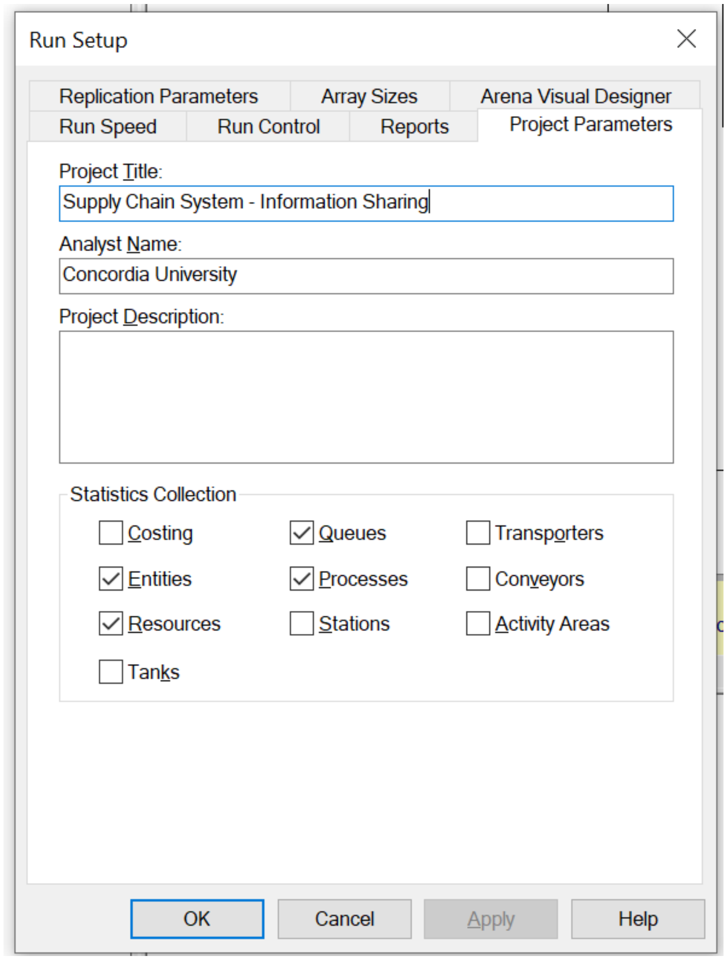


Figure 22 : Arena Run Setup

4.1.2 Events:

Systems evolve over time and to recreate the systems events are used in modelling. In simulation, apart from the initial events additional logics play a role in recreating the necessary actions for a change in state of the system. There are various ways in which events can be created in Arena, some of the key ones used in the models developed are on creation of consumer demand/entity, creating a delay, holding entities in queue and so on. Some of the main events developed are the Entity, Delay module and the Hold module. Here the Entity is from the basic process block, but the Delay module and the Hold module are from the advanced process block

4.1.2.1 Events - Entity Creation

Following steps were followed to create an entity in the model.

- The entity is created from the 'create' block in the Basic Process tab
- Once Create block is added on double clicking it takes us to the Create dialogue box where the entity name, type and expression can be entered
- Also, the unit of the entity is updated in this dialogue box as shown in the Figure:

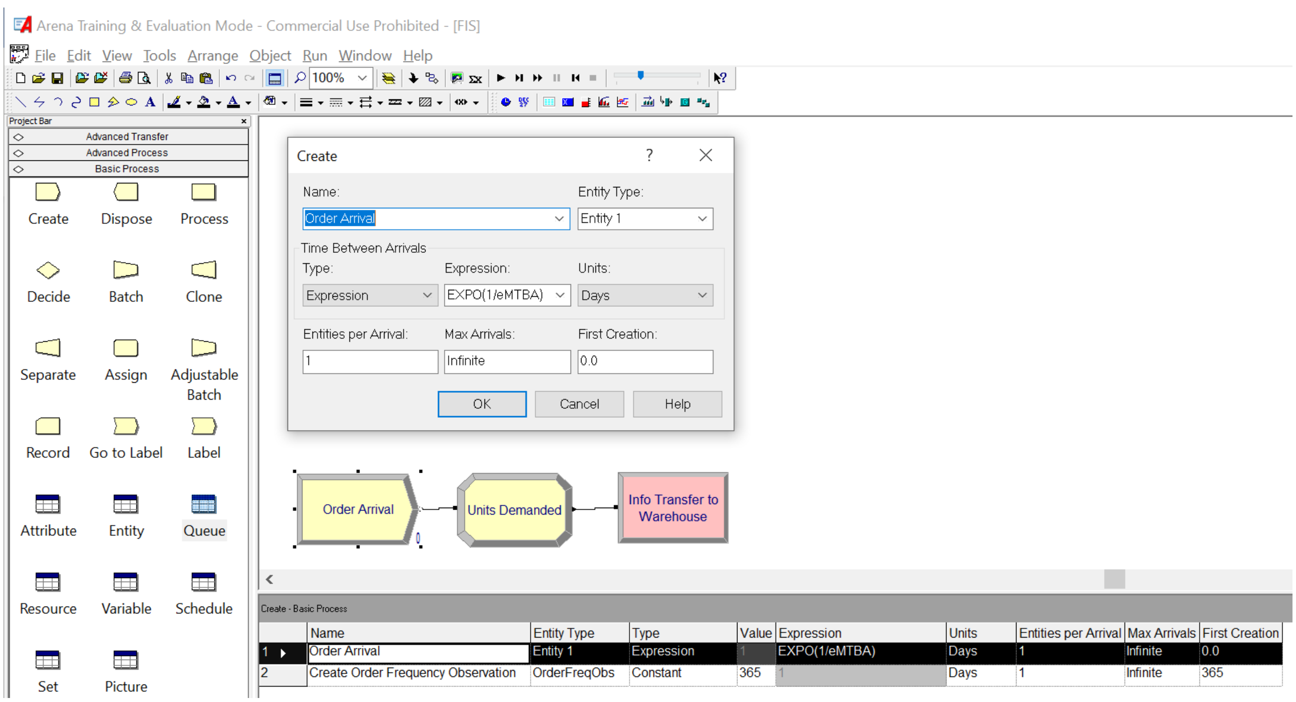


Figure 23 : Entity Creation

4.1.2.2 Events - Delay Module

Following steps were followed to generate a delay in the model

- The 'Delay' block in the Advanced Process tab is chosen

- On double clicking it the Delay dialog box opens for delay related information's to be entered in it
- The name of the delay, the delay time which could be the actual value or the variable holding the value and its corresponding units is then entered and 'Ok' is clicked.

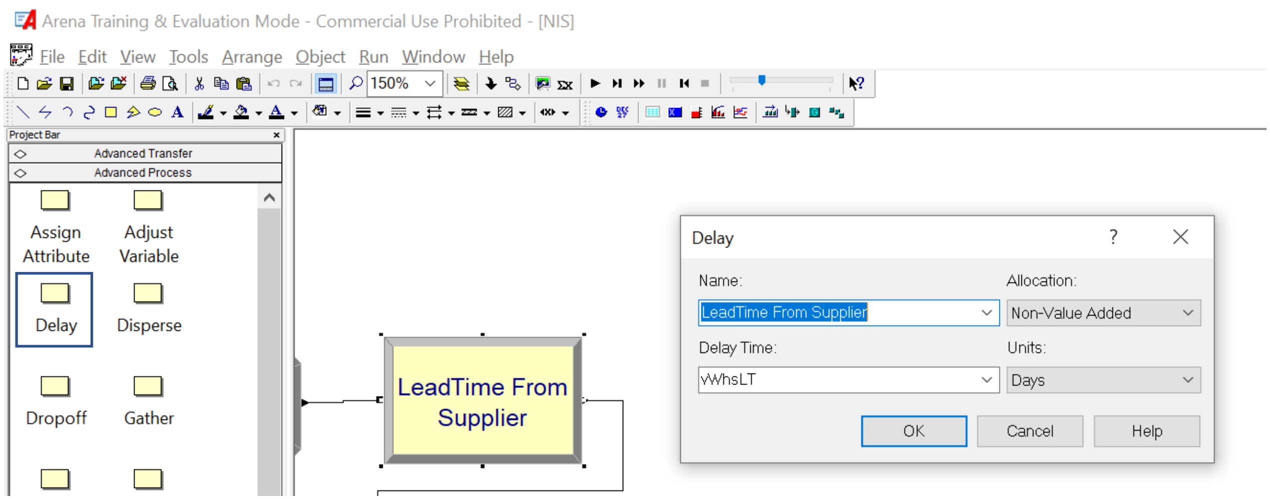


Figure 24 : Delay Module

4.1.2.3 Events - Hold Module

Following steps were followed to create the events hold module in the model.

- The entity is created from the 'create' block in the Basic Process tab
- Once Create block is added on double clicking it takes us to the Create dialogue box where the entity name, type and expression can be entered
- Also, the unit of the entity is updated in this dialogue box as shown in the Figure:

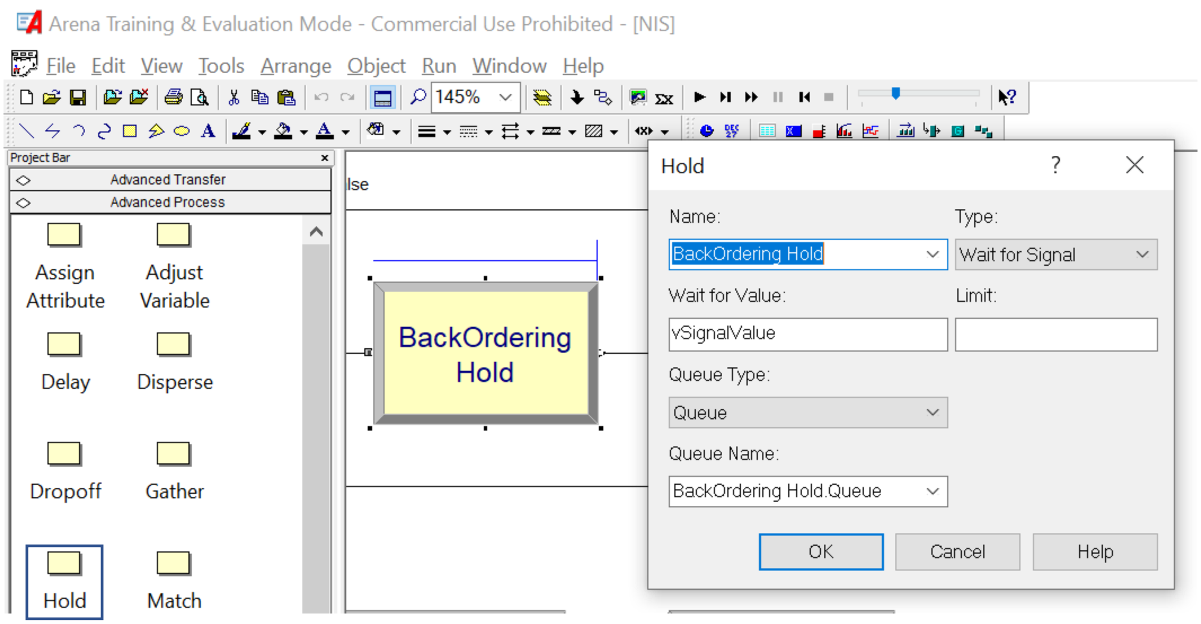


Figure 25 : Hold Module

4.1.3 Entities:

They are the objects of substantial importance and part of the system. They enter, flow through the system and finally exit. In our model the customer placing the order information is an entity. This order information flows down the model and based on the logic, appropriate events are generated and finally it exits the system via the customer when it is satisfied by the inventory in hand or by order. The other entity which is created in the model is the Order frequency observation block, this block helps to understand the number of entities that are received by the system in a year.

4.1.3.1 Entity Information

The model uses two entities and they are as follows:

- One is for the order arrival which is the order information received from the customer
- Order frequency generation which is basically calculates on the number of entities received in a year.

Figure represents on how the above-mentioned entities are configured and used in the model further configuration information is explained in section 7.6.1.

Create - Basic Process

	Name	Entity Type	Type	Value	Expression	Units	Entities per Arrival	Max Arrivals	First Creation
1	Order Arrival	Order Information	Expression	1	EXPO(1/eTBACDF)	Days	1	Infinite	0.0
2	Create Order Frequency	OrderFreqObs	Constant	365	1	Days	1	Infinite	365

Figure 26 : Entities Information in Arena

4.1.4 Attributes:

It can be defined as a characteristic of the entity. There can be many entities for a system, but an attribute is a unique representation associated with an entity and there by specifying it further with respect to its properties. In the information sharing models developed, the main attribute created to define the entity is the demand order from the consumer. This defines the order volume placed by the customer. The other attributes in the system are the stock out flag indicator and the lead time in satisfying the order with the customer. The stock out flag is set whenever there is no inventory on hand and the inventory is backordered.

4.1.4.1 Attribute Information

Steps to create an attribute:

- Under the 'Basic Process' tab the 'attribute' is chosen
- In Spreadsheet view at the end it is double clicked to add a row to include an attribute and its properties
- If the attribute needs an initialization, then the initial value is clicked, and the required initialization is provided.

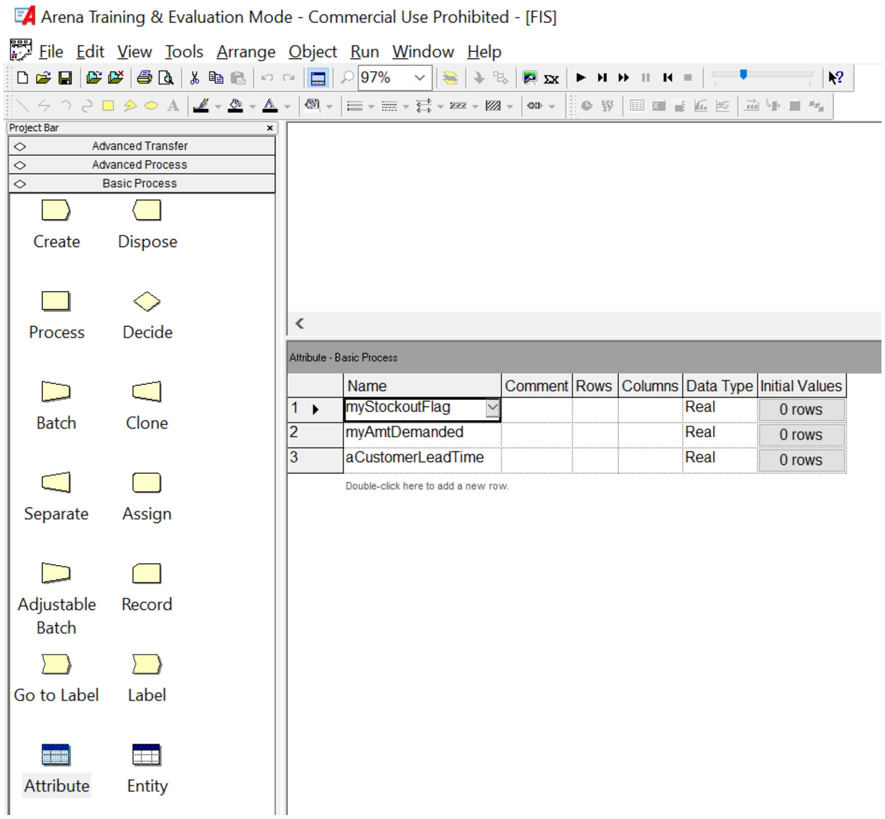


Figure 27 : Attribute Information in Arena

4.1.5 Variables:

They are part of the system and define the system in a quantitative manner and evolve along with the system. Once defined they can be changed as per the logic required thereby aiding to the change in state of the system. Variables could be scalar or as an array. The models developed have used the former declaration. All variables are ensured to start with the 'v' in front to represent it as variable in the model. Eg. vReorderPt – Re-order point variable.

4.1.5.1 Variable Information

Steps to create on variables:

- Under the 'Basic Process' tab the variable is chosen

- In Spreadsheet view at the end it is double clicked to add a row to include a variable and its properties
- If the variable needs an initialization, then the initial value is clicked, and the required initialization is provided.

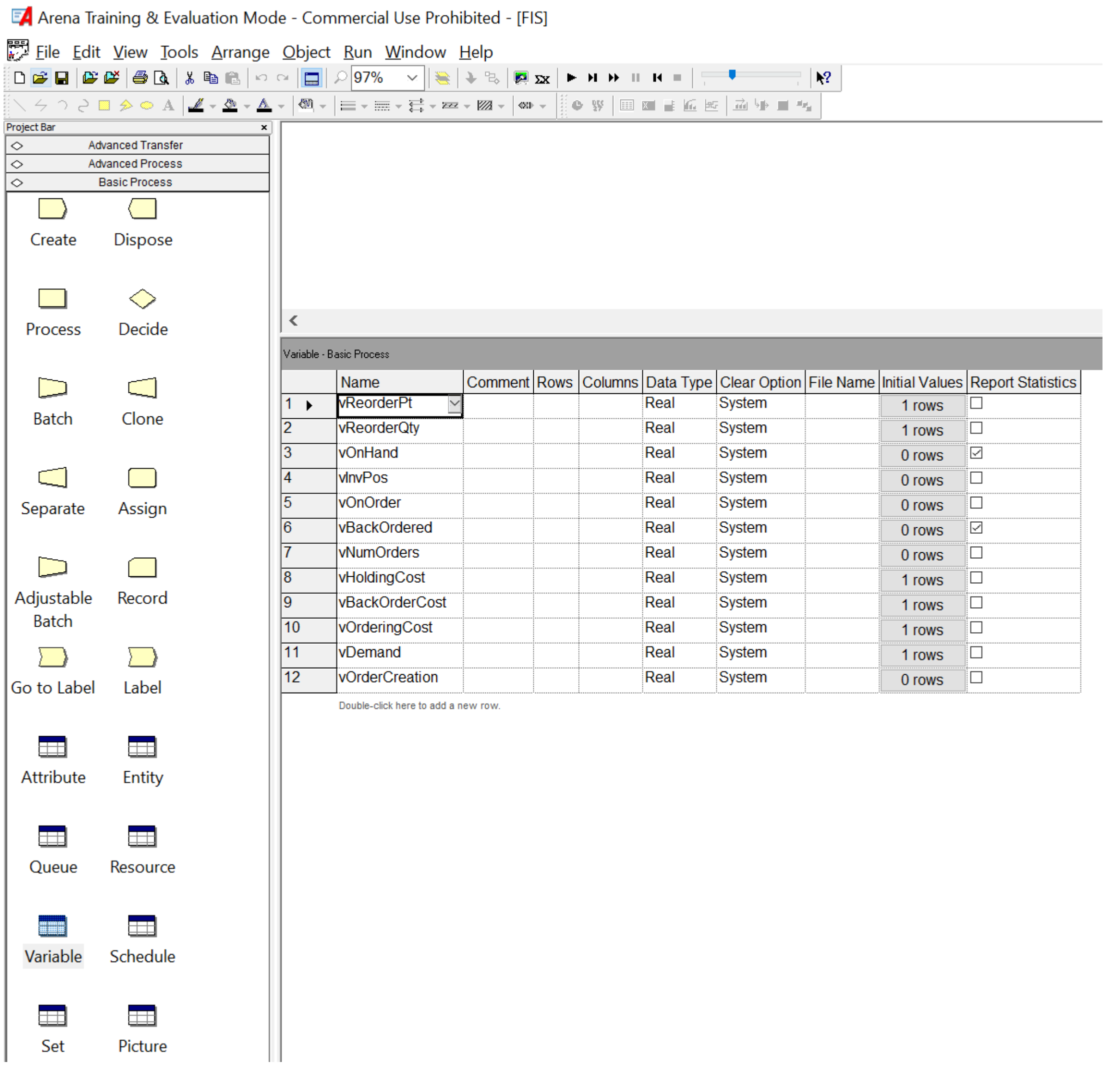


Figure 28 : Variables Information in Arena

4.1.6 Queues:

Under the basic processes of Arena one other block used in the model is the Queues. This block is used whenever the entity has a constraint and it needs for an event to happen. The queue when defined has many types in it but the model uses the ‘first in first out’ type. The queue which is used in the model is the ‘BackOrder Hold.Queue’, this queue waits till replenishment has happened either by the supplier or the warehouse so that the backorder level could be reduced, and customer is served.

4.1.6.1 Queue Information

Steps to create a queue:

- A queue is created in conjunction with the advanced process block ‘Hold’
- When a Hold block is used, its dialog box property requires for a Queue name in relation to it.
- This is provided via the basic process block ‘Queue’ tab
- When clicked in the spreadsheet view, it is double clicked to include queue and its property which is the type
- As shown in the figure the ‘first in first out’ type is usually used

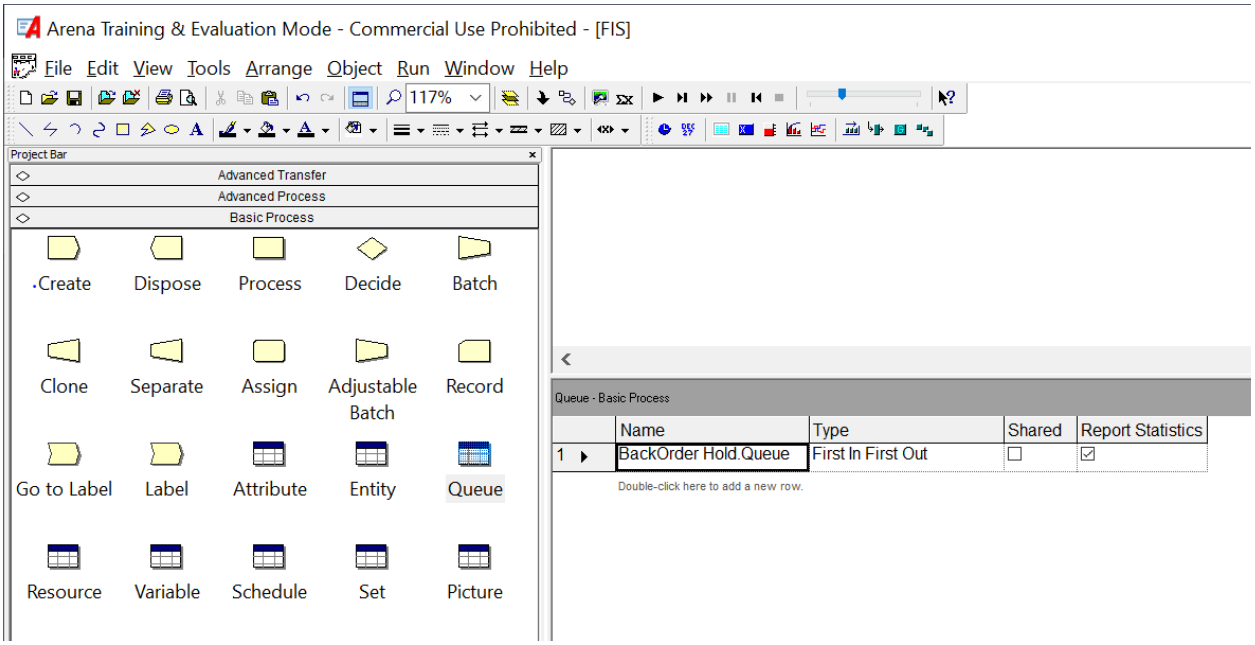


Figure 29 : Queue Information in Arena

4.1.7 Expression Information

Steps to create an expression:

- In the 'Advanced Process' tab clicking on Expression takes us to the Expression spreadsheet view
- Here on double clicking the last row the expression related name could be entered
- Clicking on 'Expression Value' takes us to its dialog box where its related mathematical expression could be updated as shown in the figure

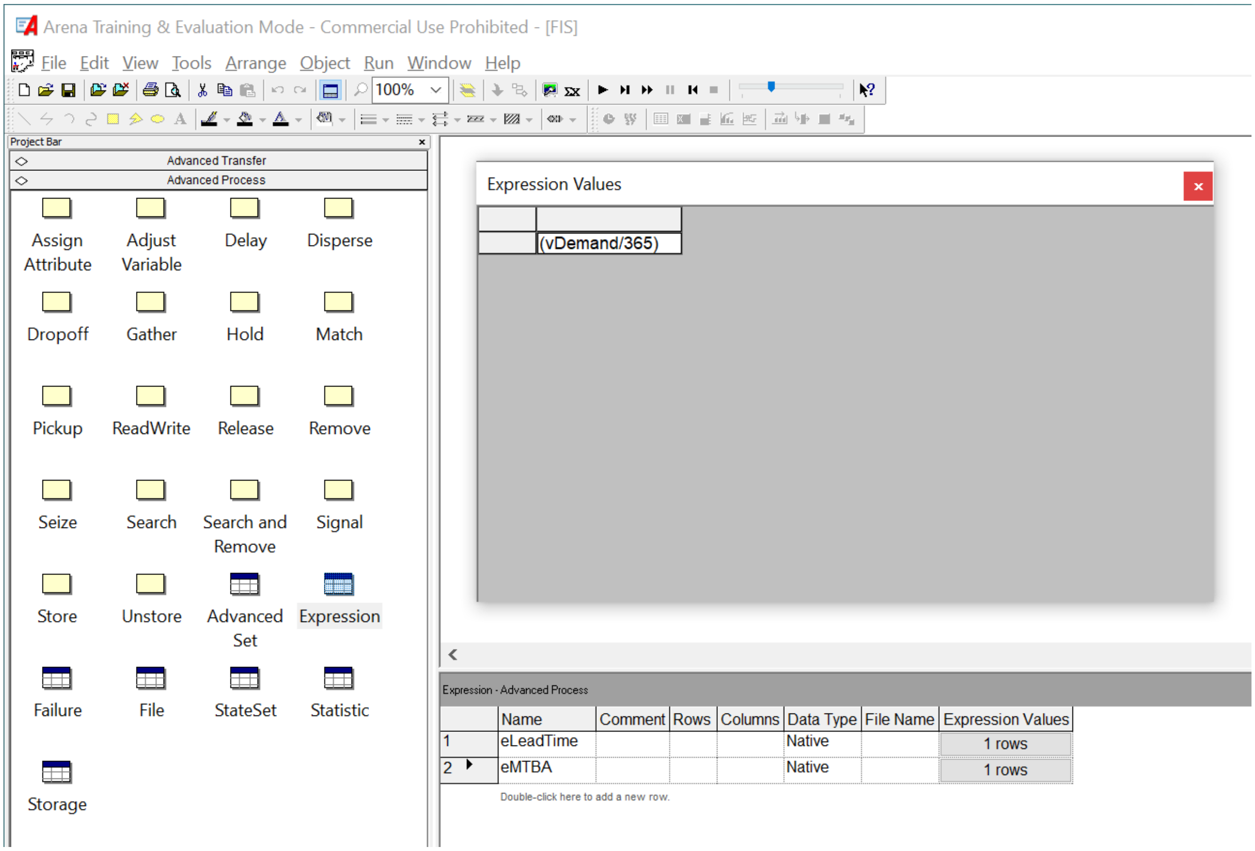


Figure 30 : Expression Information in Arena

4.2 Variable, Attribute, Queues - Arena Simulation Model

The following table 5 summarizes the definition and description of the variables, attributes and queues as used in the Arena model. It is categorized under the headings of the 'retailer' and 'warehouse'. If it is under 'common' then it is applicable to both the retailer and the warehouse.

Common	Retailer	Warehouse	Description
Variables			
vDemand			Poisson Demand Rate in a year
	vRetailerLT		Retailer Lead Time
	vQr		Retailer - Reorder Quantity
	vRr		Retailer - Reorder Point
		vWhsLT	Warehouse Lead Time
		vQw	Warehouse - Reorder Quantity
		vRw	Warehouse - Reorder Point
	vROnHand		Retailer - On Hand Quantity
	vROnOrder		Retailer - On Order Quantity
	vRBackOrdered		Retailer - Backorder Quantity
	vRInvPos		Retailer - Inventory Position
		vWhsOnHand	Warehouse - On Hand Quantity
		vWhsOnOrder	Warehouse - On Order Quantity
		vWhsBackOrdered	Warehouse - Backorder Quantity
		vWhsInvPos	Warehouse - Inventory Position
	vNumOrder_R		Retailer - Order Frequency count
		vNumOrder_W	Warehouse - Order Frequency count
	vRDemandLeadTime		Retailer - Demand Lead time
		vWhsDemandLeadTime	Warehouse Demand Lead time
ADI			Advance Demand Information Flag
vHoldingCost			Holding Cost
vBackorderCost			Backorder Cost
vOrderingCost			Ordering Cost
Attributes			
aAmountDemanded			Amount Demanded from Consumer
	aRetailerSOFlag		Retailer Stock Out Flag
		aWhsSOFlag	Warehouse Stock Out Flag
Queues			
	Retailer BackOrder Hold		Retailer Back log hold Queue
		qWhsBackLogHold	Warehouse Back log hold Queue

Table 5: Variables, Attributes and Queues - Arena Definition

4.3 Replication Parameters tab Setup

In the Arena Environment, once the project is created the next step would be to setup the 'Replication Length'. Replication Length is the number of times or how long the simulation is required to be run for effective results.

- Clicking on 'Run' and 'Setup' takes us to the 'Run Setup' page.
- In the 'Run Setup' page choose the 'Replication' Tab. For this project the 'Replication' tab has been updated as per the figure.

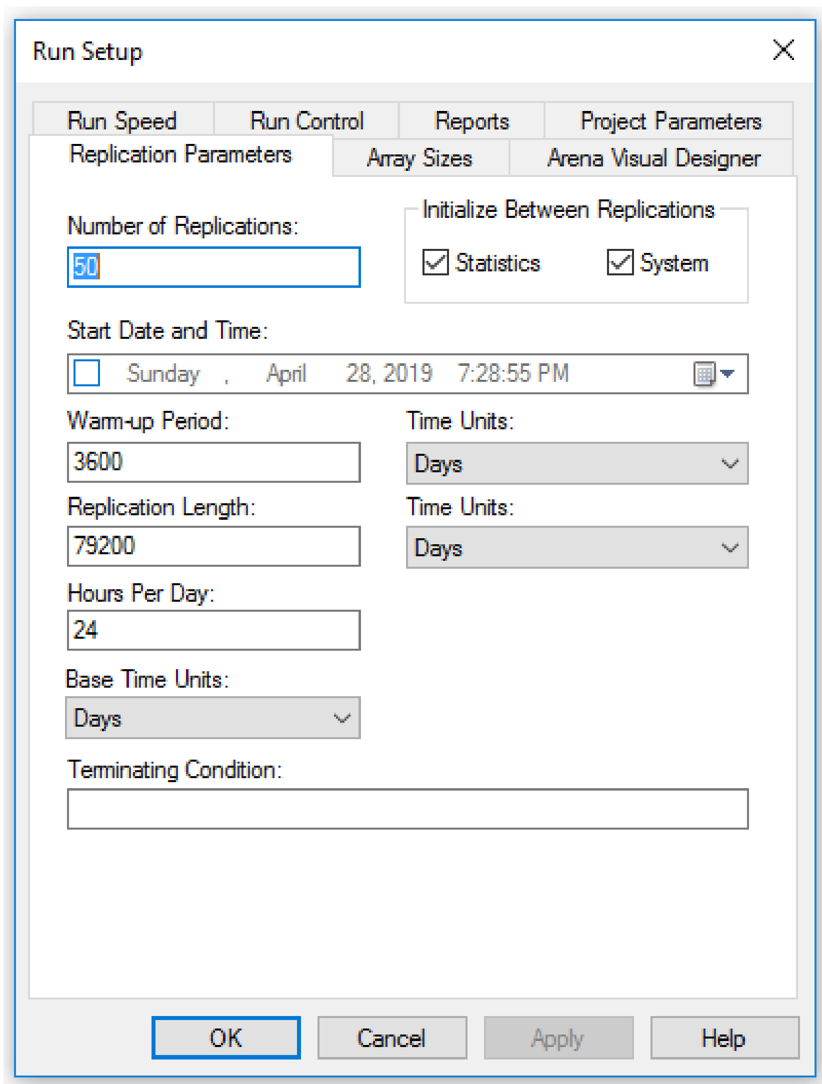


Figure 31 : Run Setup – Replication Parameters Tab

4.4 (r,Q) Model Explanation

The information sharing model is based on the (r,Q) inventory policy among the retailer and the warehouse. The Arena model of the (r,Q) inventory policy which is used in the processing of the orders is work of (Rossetti, 2015) which has been updated to suit the needs for the information sharing concepts. But this model has been used and extensively updated and expanded for further applications for all the three scenarios. So, this section shall provide a background with respect to this model. The model is explained in three parts the filling logic, backordering logic and replenishment logic.

The Filling Logic:

This logic receives the incoming order from the customer, validates it with its current on-hand inventory, and if the inventory requested is available it immediately fills the demand requested by the customer, records the stockout status, then it sees whether it has reorder or there is still sufficient inventory available on hand. If available, it exits the system. If not, it goes ahead to reorder the required inventory from the supplier. The author (Rossetti, 2015) has used a 'create' block for the entity arrival, then 'assign' blocks for the assignment of inventory levels and order information, then 'decide' block with a '2-way by condition' type for decision on whether there is sufficient inventory on hand or whether required to re-order. Figure 32 represents this flow as modeled in Arena.

The first step in this model is to create an entity through the 'create' block with the mean time between arrival set to exponential distribution for the demand rate. The demand is considered for a year so the demand in the case study for the information sharing problem so the 'expression' in the create module dialogue is entered as "EXPO(1/vDemandRate)" where the vDemandRate is a value considered for the experiment.

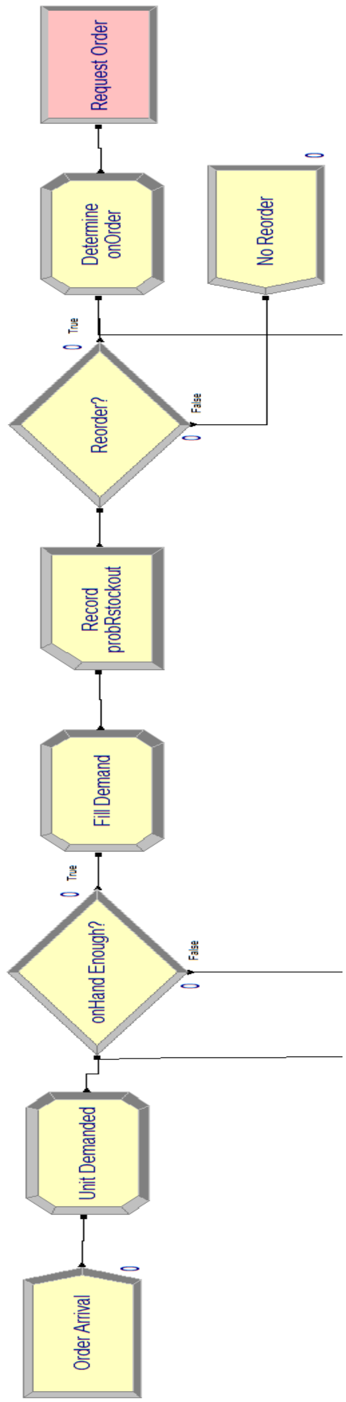


Figure 32 : Filling Logic (Model Source: Rossetti, 2015)

Back Ordering Logic:

Whenever there is not enough inventory on hand to satisfy the customer then the order information goes through the backordering logic. Here the backorder quantity is calculated and then owing to this new order whether a reorder is required or not is checked then the required quantity goes through the ordering path and then waits, if no order is necessary still the system waits until a replenishment happens from the supplier.

The blocks used to implement this logic would be the assign, decision, separate and the hold block. Assign blocks in this logic identify on the backordering quantity and later when the replenishment has happened it updates on the backorder quantity with the customer. The decision block is same as in the filling logic with the '2-way condition type'. The separate block is to split for execution in two ways based on the original entity flow. The type chosen is to "Duplicate Original", so there are two paths the duplicates would exit out of the duplicate path and the Original via the original path. The entities enter and exists in the first come first serve basis in the queue. Here it waits for the signal value 1 to be generated so that it can exist the queue the signal value 1 is set whenever the replenishment is complete, and the quantity ordered is available for refill to the customer. Figure 33 shows the model flow of this detailed backorder logic.

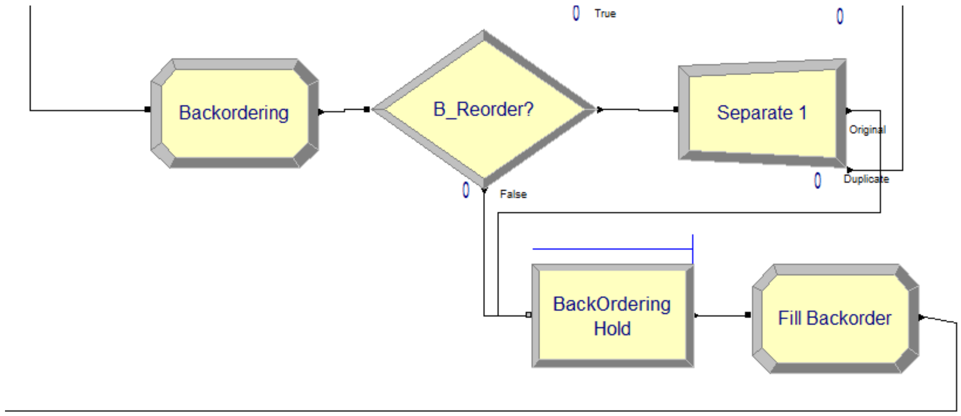


Figure 33 : Back Ordering Logic (Model Source: Rossetti, 2015)

Replenishment Logic:

The order placed then goes through the replenishment logic of the model. This part of the model waits for the supplier lead time to be met and then on receiving the shipment signals, it replenishes the on-hand inventory level. It also signals to the backorder queue stating that the shipment has arrived, and the backorder quantity could also be met and finally it exits the system.

The blocks used here are the delay, assign, record, signal and dispose. The delay block replicates the scenario of supplier lead time. The delay time is entered in the dialogue box and this is the duration until when it creates a delay before moving on to the next block. The delay here is just a representation as it were supplier working to get the order to the retailer or warehouse. Once the delay is complete the assignment block updates on the order information as being received and updating the on-hand inventory level to the order quantity requested. Then there is the record block which records on the time instant and calculates the time interval between the instant the order was placed to this instant and outputs it as the Demand Lead Time. The signal block updates with a signal value to the backorder queue indicating that the replenishment has happened. With these actions the reordering is complete and via the dispose block the entity is exited from the system.

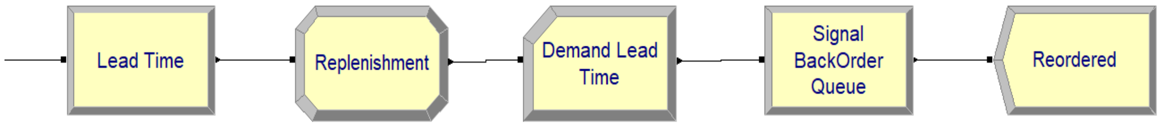


Figure 34 : Replenishment Logic (Model Source: Rossetti, 2015)

Performance Measure collection logic:

Now with the core logic model done, in order to collect data over an interval this performance measure logic has been developed by the author. The order interval of collection is customized for the information sharing models to be for a year and this information is provided on frequency observation entity. So every 365 days the measure happens. It is mainly for measuring the order frequency which is number of orders received in a time interval. So, with the variable vNumOrder the number of orders is continuously collected and after every 365 days this variable total value is recorded and reset to 0. With this variable the Order Frequency is understood which also confirms to us whether the demand set is being met by the model.

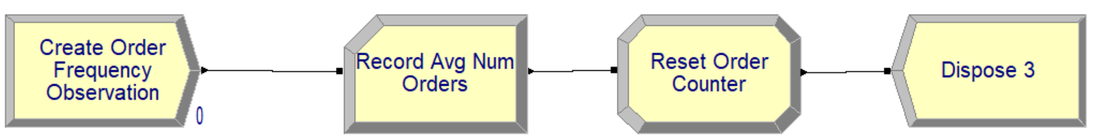


Figure 35: Performance Measure collection Logic (Model Source: Rossetti, 2015)

4.5 Information Sharing model

The model details of the three scenarios are detailed in this section.

4.5.1.1 No Information Sharing model

This model follows the concept as explained in the section 3.2.1. There are two parts in it the retailer part and the warehouse part. Both follow the (r,Q) policy as explained in detail in the previous section. Here the incremental logic was the connect between the retailer and warehouse to operate based on the entity configured for it. Figure 36 shows the model used for the retailer logic.

In this retailer logic, it can be observed that when the retailer is out of stock he raises request to the warehouse module via the ‘Route’ block. Figure 37 shows the logic for the warehouse. Here via the ‘Station’ block the retailer and the warehouse logic flow is established.

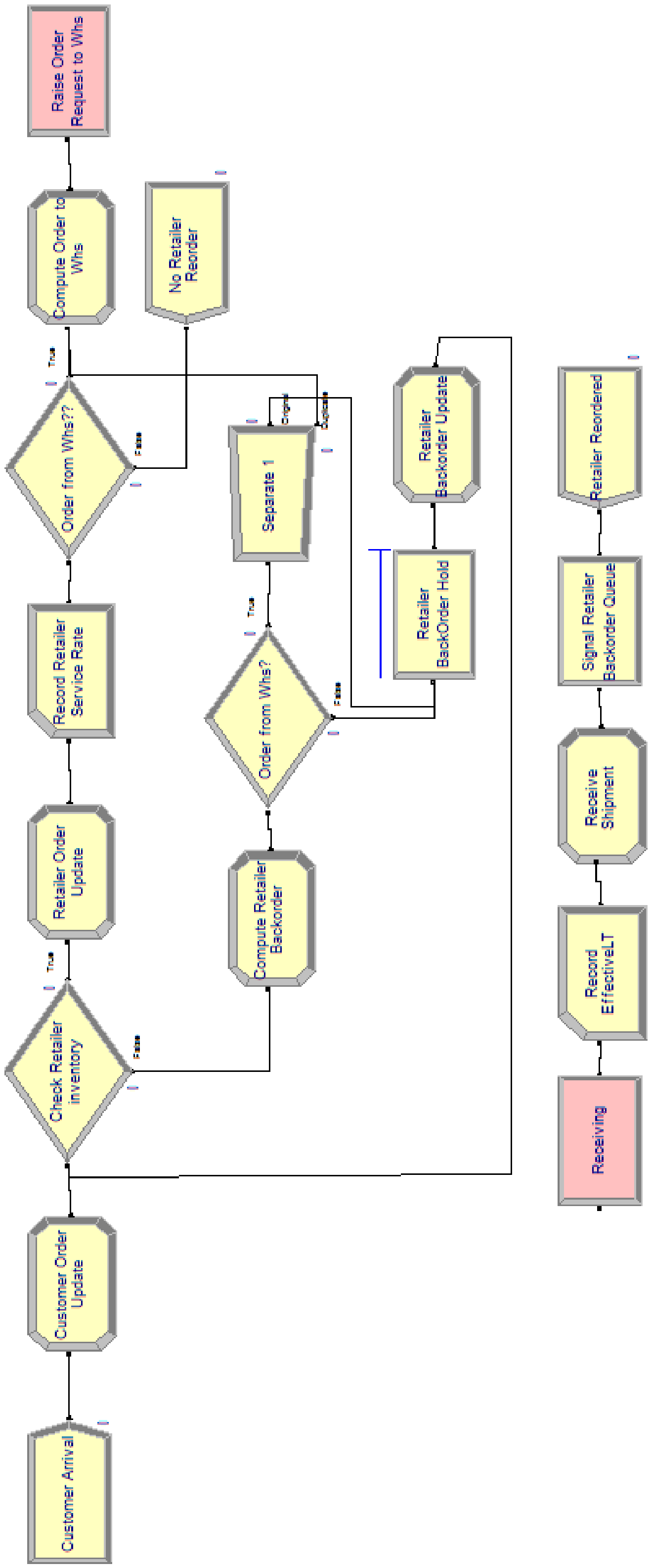


Figure 36: Retailer Logic

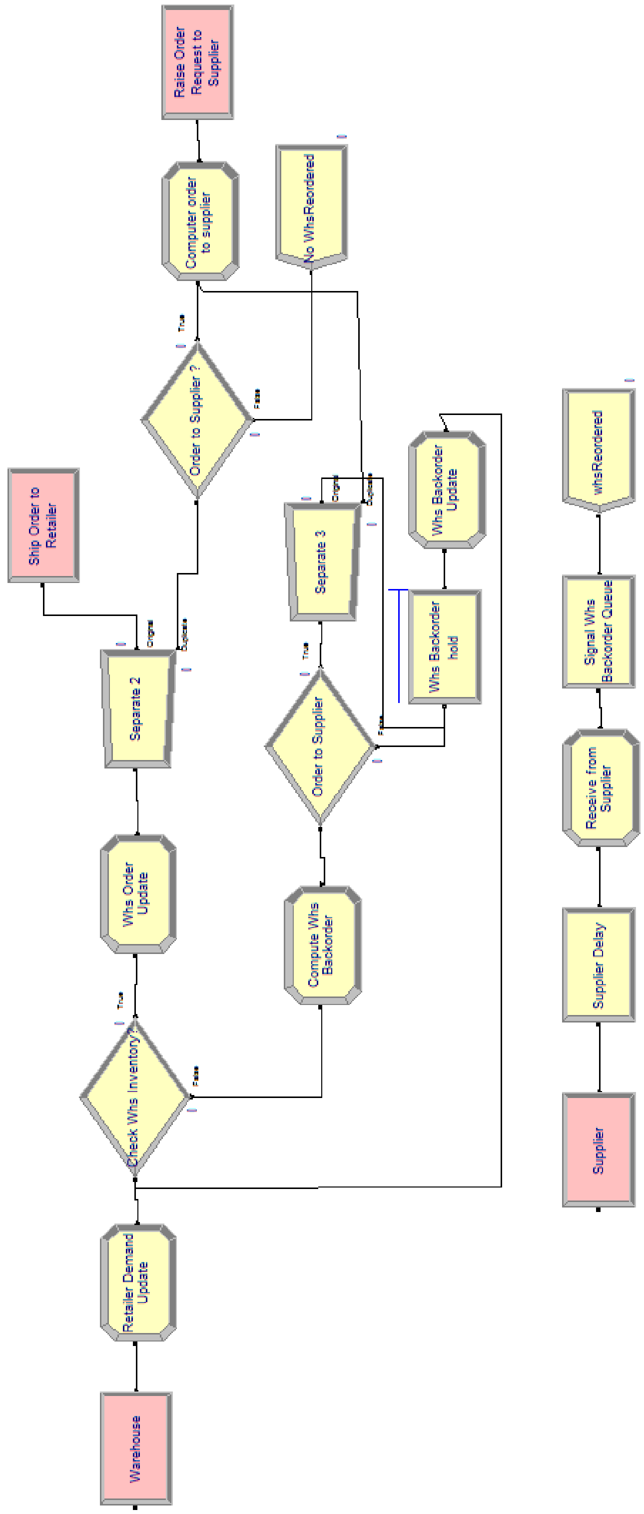
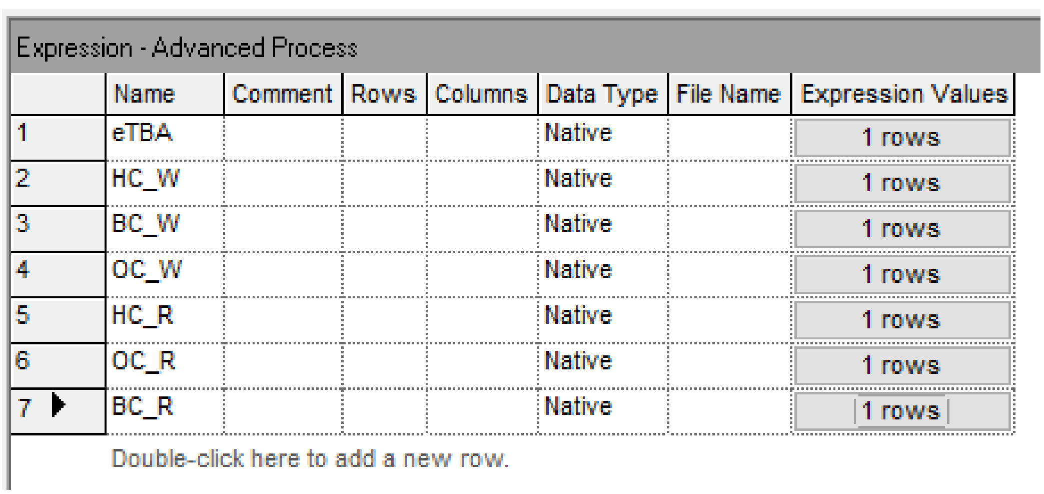


Figure 37: Warehouse Logic

A challenge in this model is on the collection of statistics. The model has to display or provide information on the cost calculations. In this model the statistics with respect to the cost is implemented via the equations (12) to (16) via two main blocks in Arena.

The Expression Block: It is a block in the Advanced Process of Arena. Here any times equations that require to be fed to the block or required for statistics purpose could be entered here with an associated name aligned to it. For this model, the cost calculations have been generated via the expression block. As seen in figure 38 all the cost values are reflected here with respect to both the retailer and the warehouse. The equation is entered via the expression values dialogue box when the row against the name is clicked.


Expression - Advanced Process

	Name	Comment	Rows	Columns	Data Type	File Name	Expression Values
1	eTBA				Native		1 rows
2	HC_W				Native		1 rows
3	BC_W				Native		1 rows
4	OC_W				Native		1 rows
5	HC_R				Native		1 rows
6	OC_R				Native		1 rows
7	BC_R				Native		1 rows

Double-click here to add a new row.

Figure 38: Expression Block

The expression value entry is shown in Figure 39. Here the function DAVG() is used. This function returns the average of the time persistent value. So, product of the HC and the average on hand value would return the holding cost of the warehouse or the retailer. All other costs are calculated in the same manner.

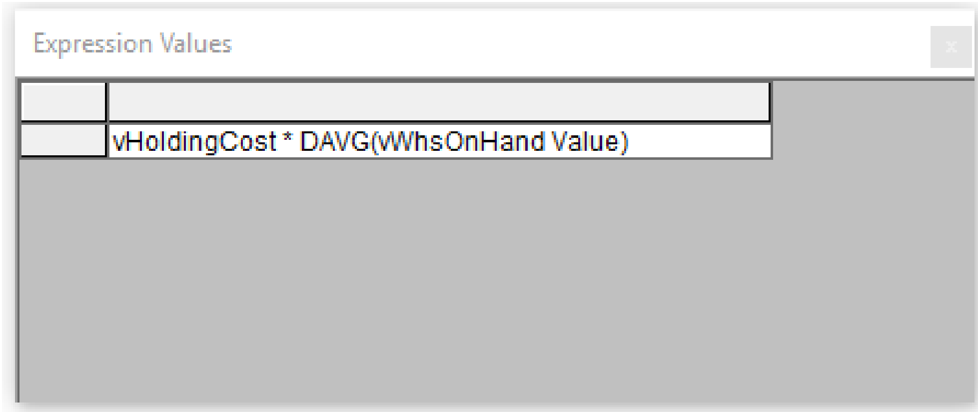


Figure 39: Expression Value Dialogue in Expression Block

Once the costs are available in the expression block, these expressions are used in the statistics block in Arena to output the desired result. Statistic is a block in the Advanced Process tab in Arena. The screen of it is as shown in the Figure 40. From the expressions previously entered, the TC of the retailer, warehouse and the supply chain system are given as expression so it can be generated as output. Here the OVALUE() function is used. The OVALUE () function returns the last recorded value of the specified output.

Statistic - Advanced Process

	Name	Type	Expression	Report Label	Output File
1	TC_W	Output	HC_W + BC_W + OC_W	TC_W	
2	TC_R	Output	HC_R + BC_R + OC_R	TC_R	
3	TC_SC	Output	OVALUE(TC_W) + OVALUE(TC_R)	TC_SC	

Double-click here to add a new row.

Figure 40: Statistic Block

4.5.1.2 Partial Information Sharing model

The PIS model follows the NIS model similarly but it has been updated mainly to include two main logics. Those are the ADI check logic and the due date delivery logic. In the ADI check logic, as soon the entity is created the retailer checks for the advance information from the customer on the demand lead time and the due date delivery. Based on it, it changes its supply lead time and flags the information to the warehouse. The warehouse once receives request from the retailer, would first use the ADI logic to check if the ADI is received and based on the ADI information it will as well update the supply lead time as per the equation L = $Ls - L_D$. This causes a reduction in the supply lead time for both the retailer and the warehouse, thereby reducing the backorder level when compared to the NIS model. This logic implementation is shown in the Figure 41.

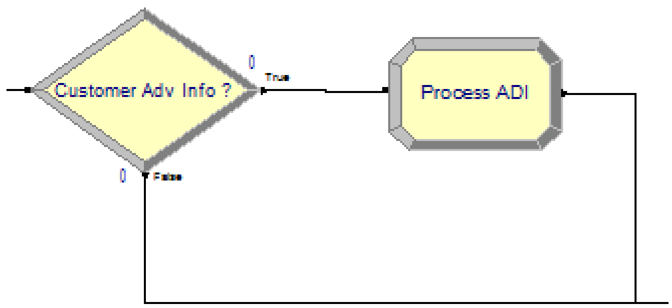


Figure 41: ADI check logic

The other logic is about the due date delivery logic which is shown in Figure 42. This logic is basically introduced to satisfy the requirement on customer to receive his shipment only after his demand lead time and no other time in advance or later. A late arrival may land up in penalization but an advance (early) arrival of order is also not in customer's interest as it may increase the holding cost of the customer. So, this logic is introduced to simulate this condition and it has been added whenever a replenishment happens to the customer. The decide block checks on whether it is the due date. If it is not the due date, it delays the delivery and then flags for customer shipment. This logic is in both the retailer as well as in warehouse logic.

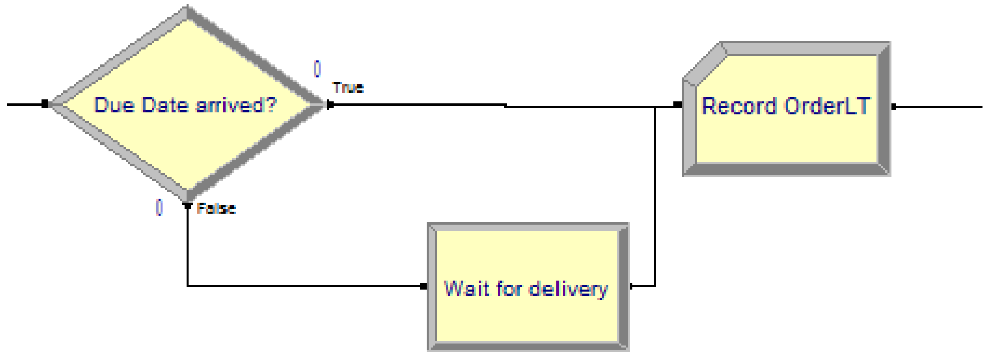


Figure 42: Due date delivery logic

4.5.1.3 Full Information Sharing model

This model is as explained in section 3.3.3. The incremental changes done was to create a push/pull of the order information so close to a VMI concept could be simulated here. As shown in the Figure 43 the retailer receives the customer order information and signals on information shared to the warehouse. The warehouse pulls this information and immediately process it as per the (r,Q) inventory process model and delivers it to the retailer.

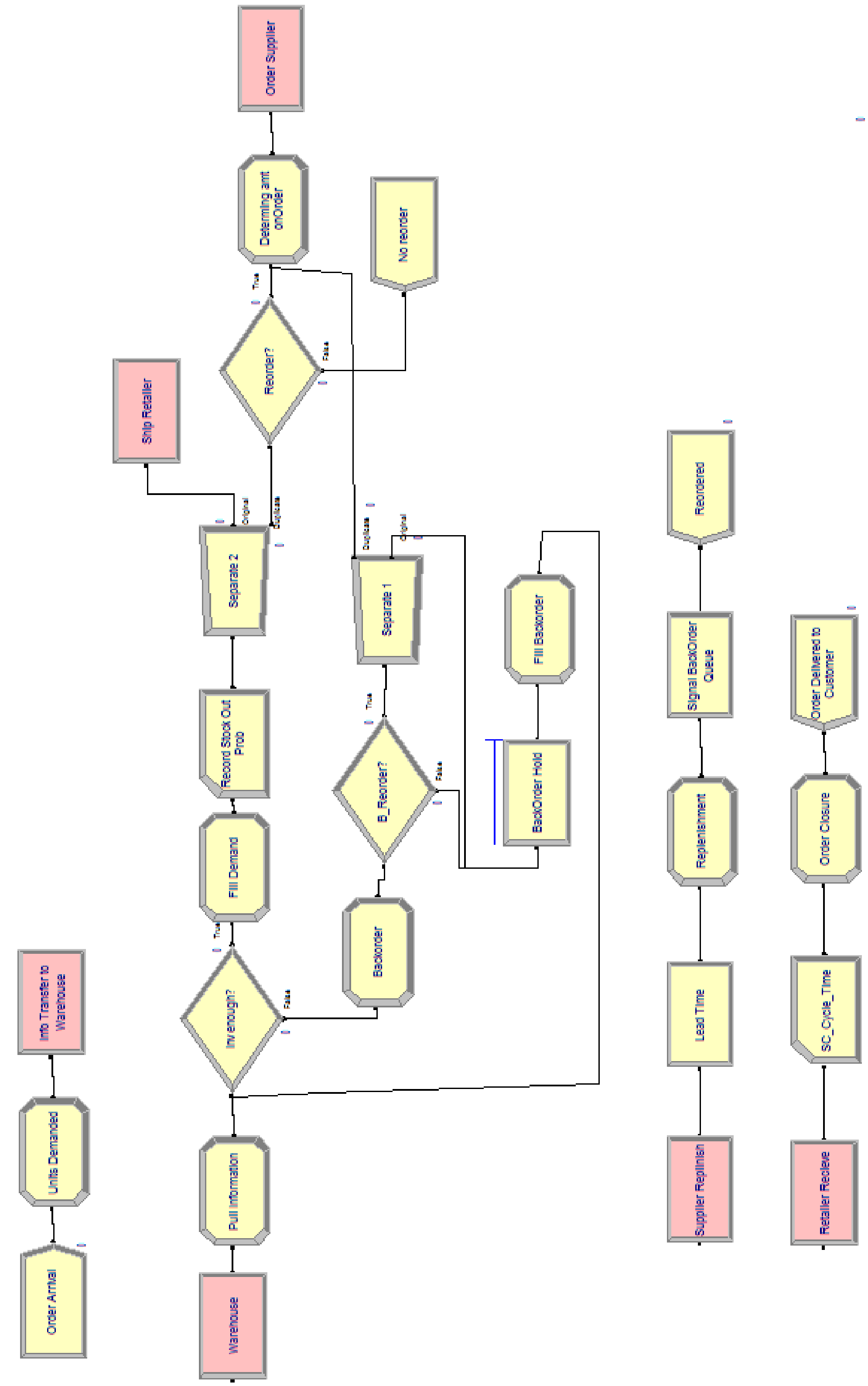


Figure 43: (Model Adapted: Rossetti, 2015)

4.6 Process Analyzer Output

When multiple experiments need to be run for certain number of replications, the tool used is the process analyser tool. The models generated uses the process analyser tool for two main purposes, the first one was to verify the model generated and the next one was to conduct the sensitivity analysis via the process analyser. It is a tool provided by Arena to check on multiple scenarios. The tool is a simple on with three areas in it, the region in which property of the project is given, the experiments execution region and the region in which the charts are displayed. Figure 44 shows the Process Analyzer tool from Arena

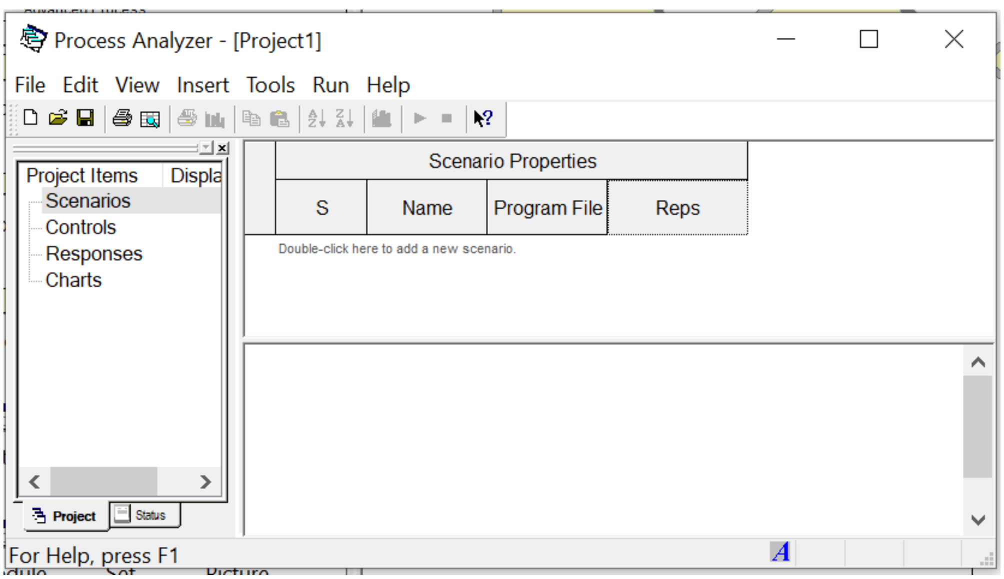


Figure 44: Process Analyzer Tool

Here the scenarios were created by double clicking on the experiment execution region and the property dialogue information was filled, like as shown in Figure 45.

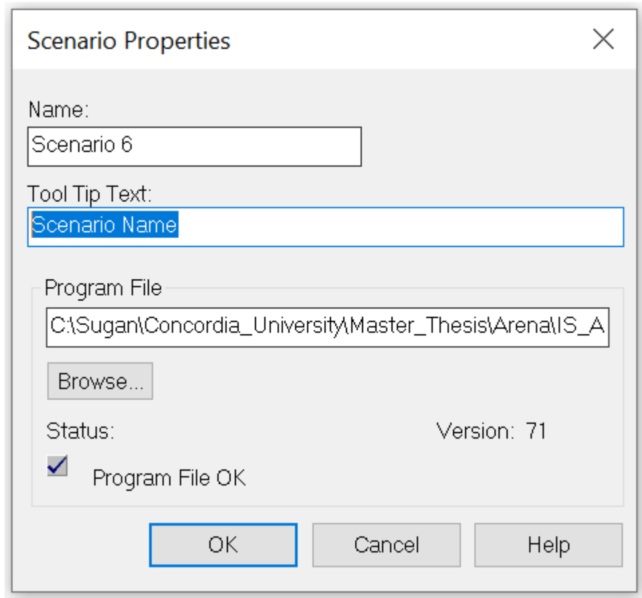


Figure 45: Scenario Property

Once the line item is created the scenarios and controls were provided. In the verification and validation of the model, a total of 9 scenarios were considered. The controls were mainly based on the demand, reorder point and the reorder quantity. These controls based on the mathematical calculations; the values were entered in the process analyser. These inventory control values were the optimum values with respect to both the retailer and the warehouse in the case of the NIS or PIS. Based on these inputs, the output response which is the total cost of the supply chain system is observed. Figure 46 shows an example on how the controls were set and response was received after execution of the experiments.

	Scenario Properties				Controls			Response
	S	Name	Program File	Reps	vDemand	vReorderQty	vReorderPt	TotalCost
1		Scenario 1	26 : FIS.p	10	5.0000	2.0000	1.0000	96.609
2		Scenario 2	26 : FIS.p	10	20.0000	4.0000	5.0000	226.800
3		Scenario 3	26 : FIS.p	10	50.0000	7.0000	8.0000	288.195
4		Scenario 4	26 : FIS.p	10	220.0000	15.0000	31.0000	591.546
5		Scenario 5	26 : FIS.p	10	500.0000	22.0000	67.0000	873.365
6		Scenario 6	26 : FIS.p	10	2200.0000	47.0000	283.0000	1822.133
7		Scenario 7	26 : FIS.p	10	5000.0000	71.0000	635.0000	2758.817
8		Scenario 8	26 : FIS.p	10	5500.0000	74.0000	697.0000	2880.654
9		Scenario 9	26 : FIS.p	10	6000.0000	77.0000	760.0000	3022.011

Figure 46: Scenario, Controls, Response

CHAPTER 5:

NUMERICAL ILLUSTRATION

In this chapter, we demonstrate various supply chain information scenarios through the discrete event simulation model. A small and simple case scenario is considered and this scenario is applied to all information models of collaboration. Let us consider a two-echelon supply chain. Last year data collected for a commodity has an annual demand *(D)* at a Poisson rate of 5 container units per year. The cost of a commodity container unit is $150, and if an interest rate of 20 percent is applied, the annual holding cost *h* becomes 0.2($150) = $30 per year. Let's consider that it takes a total time of 45 days to receive a replenishment order. The purchase order for the commodity is set at about $15, and the annualized cost of a backorder is about b = $100 per year. The demand model follows a Poisson Distribution. Also, there is a fixed transportation time between the warehouse and the retailer of 1 day. This base scenario has been applied to all three levels of partnership and the output of the results has been documented as per the below sections. The 'rQInventoryModel,xls' spreadsheet of the author (Rossetti, 2015), consisting of macros to support in calculating the inventory levels has been adapted to calculate for various values of demand and between the retailer and warehouse, ADI concept and retailer warehouse collaborations.

The Numerical Analysis has been carried out to verify and validate the model. For verification the above scenario for a known value of demand is verified and then it is tested for various values ranging from 5 to 6000. The output of the model against this range is checked as part of the sensitivity analysis to validate the models. The below sections detail on both these evaluations.

5.1 Model Verification

Verification is carried out to ensure the correctness of the model whether the logics executed are working as intended and the values generated from it is close to the values expected or whether a tolerance exists when checked for extreme values. The three models in discussion were verified with various inputs and from the outputs generated, and the closeness to the calculated values was verified. To understand the verification process, a sample with demand rate 5 is analysed for all three levels.

No information sharing:

No Information Sharing		
	Expected	Actuals
Retailer Order Frequency	2.500	2.522
Warehouse Order Frequency	2.500	2.522
Retailer Back Order Level	0.000	0.003
Warehouse Back Order Level	0.017	0.025
Retailer On hand level	1.470	1.438
Warehouse On hand Level	1.900	1.903
TC_R	81.620	81.310
TC_W	96.160	97.466
TC_SC	177.780	178.780

Table 6: NIS Verification

5:50:04PM **User Specified** April 26, 2019

No Information Sharing Replications: 10

Replication 10 Start Time: 3,600.00 Stop Time: 79,200.00 Time Units: Days

Tally

Expression	Average	Half Width	Minimum	Maximum
Record CustomerServeRate	0.9713	0.009213107	0	1.0000
RetailerOrderFrequency	2.5217	(Insufficient)	0	6.0000
WhsOrderFrequency	2.5217	(Insufficient)	0	6.0000

Interval	Average	Half Width	Minimum	Maximum
Customer Lead Time	4.0547	0.565907873	2.2099	43.6684

Time Persistent

Variable	Average	Half Width	Minimum	Maximum
vRBackOrdered	0.00341018	(Insufficient)	0	2.0000
vROnHand	1.4381	0.032105389	0	2.0000
vWhsBackOrdered	0.02552511	(Insufficient)	0	4.0000
vWhsOnHand	1.9029	0.035644397	0.5000	2.5000

Output

Output	Value
TC_R	81.3096
TC_SC	178.78
TC_W	97.4658

Replication 2 Start Time: 3,600.00 Stop Time: 79,200.00 Time Units: Days

Figure 47: NIS – Arena Report

Partial information sharing:

Partial Information Sharing		
	Expected	Actuals
Retailer Order Frequency	2.500	2.488
Warehouse Order Frequency	2.500	2.488
Retailer Back Order Level	0.000	0.000
Warehouse Back Order Level	0.000	0.000
Retailer On hand level	1.495	1.491
Warehouse On hand Level	1.368	1.463
TC_R	82.360	82.038
TC_W	79.000	84.227
TC_SC	161.360	166.265

Table 7: PIS Verification

6:06:34PM **User Specified** April 27, 2019

No Information Sharing

Replications: 1

Replication 1

Start Time: 3,600.00 Stop Time: 79,200.00 Time Units: Days

Tally

Expression	Average	Half Width	Minimum	Maximum
Record CustomerServeRate	1.0000	0.000000000	1.0000	1.0000
RetailerOrderFrequency	2.4879	(Insufficient)	0	6.0000
WhsOrderFrequency	2.4879	(Insufficient)	0	6.0000

Interval	Average	Half Width	Minimum	Maximum
Customer Lead Time	9.9861	(Correlated)	0.9139	10.0000

Time Persistent

Variable	Average	Half Width	Minimum	Maximum
vRBackOrdered	0	(Insufficient)	0	0
vROnHand	1.4906	0.030299053	0	2.0000
vWhsBackOrdered	0.00014699	(Insufficient)	0	2.0000
vWhsOnHand	1.8631	0.007157552	0	2.0000

Output

Output	Value
TC_R	82.0377
TC_SC	166.26
TC_W	84.2268

Figure 48: PIS – Arena Report

Full Information Sharing:

Full Information Sharing		
	Expected	Actuals
Warehouse Order Frequency	2.500	2.488
Warehouse Back Order Level	0.017	0.020
Warehouse On hand Level	1.900	1.894
TC_SC	96.161	96.151

Table 8: FIS Verification

10:36:56PM **User Specified** April 26, 2019

Unnamed Project Replications: 10

Replication 1 Start Time: 3,600.00 Stop Time: 79,200.00 Time Units: Days

Tally

Expression	Average	Half Width	Minimum	Maximum
CustomerServeRate	0.9036	0.025499900	0	1.0000
OrderFrequency	2.4879	(Insufficient)	0	6.0000

Interval	Average	Half Width	Minimum	Maximum
SC LeadTime	1.4619	0.472940764	0	39.6422

Time Persistent

Variable	Average	Half Width	Minimum	Maximum
vBackOrdered	0.02005291	(Insufficient)	0	3.0000
vOnHand	1.8942	0.039164414	0	3.0000

Output

Output	Value
BackorderCost	2.0053
HoldingCost	56.8266
OrderingCost	37.3188
TotalCost	96.1507

Replication 10 Start Time: 3,600.00 Stop Time: 79,200.00 Time Units: Days

Figure 49: FIS – Arena Report

5.2 Model Validation

The models as explained in the previous section has been run for 79200 days with a replication of 10 as settings. But still to ensure on stability it has been executed for a max replication of 50 and the result was found to be the same. 50 Reps was found to be reasonable to check for because the number of days each rep gets executed for is high. Each of the scenarios will show outputs with both 10 and 50 reps executions.

5.2.1 Scenario 1 – NIS

This 'No Information Sharing' scenario is the base with which the other scenarios are evaluated or analysed. Since this is the base, many executions (iterations) were done to ensure that the actual values are closer to the theoretical values. Table 9 reflects on the theoretical deductions created before feeding the input to the simulation model for this scenario. For a demand rate, set the optimal reorder point and reorder quantity at both the retailer (Rr and Qr). The warehouse (Rw, Qw) is found and fed as controls to model. The expected response (spreadsheet results) are evaluated against the model outputs.

Retailer Input Parameters

D	LTr	θr	h	b	o
5	2.2099	0.0303	30	100	15

Retailer Optimum Response

Qr	CR	Z	Rr
2.236	0.769	0.736	0.158

Warehouse Input Parameters

D	LTw	θw	h	b	o
5	45	0.6164	30	100	15

Warehouse Optimum Response

Qw	CR	Z	Rw
2.236	0.769	0.736	1.195

Total Cost Calculation of the Supply Chain for various Demand

Control						Response Expected		
D	Qw	Rw	Qr	Rr	LTr	TCr	TCw	SC_TC
5	2	1	2	0	2.2099	81.62	96.16	177.78
20	4	4	4	0	1.3808	147.82	198.74	346.56
50	7	8	7	0	1.3668	221.85	288.74	510.59
220	14	30	14	0	1.2822	440.30	569.13	1009.43
500	22	67	22	2	1.1444	699.71	872.32	1572.03
2200	46	283	46	8	1.0663	1470.88	1827.33	3298.21
5000	71	635	71	17	1.0404	2220.38	2765.17	4985.55
6000	77	759	77	20	1.0563	2420.08	3037.43	5457.51

Table 9: NIS – Input and Output Parameters

After Table 9 has been generated, the input controls are fed to the models and to run multiple test cases the process analyzer tool is used. The model is repeated for 10 iteration and has a warm up period of 3600 days and a replication length of 79200 days. So, executing model for longer days and for various values of demand iteratively helps us to validate the model better. The process analyser output is as shown in Figure 50. The responses are found to be close to the mathematical calculation developed.

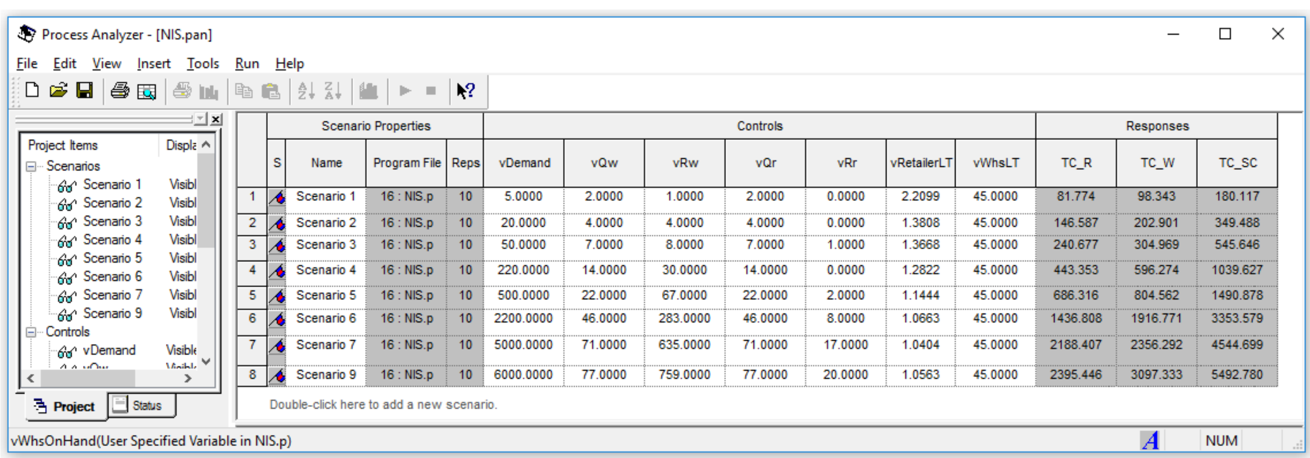
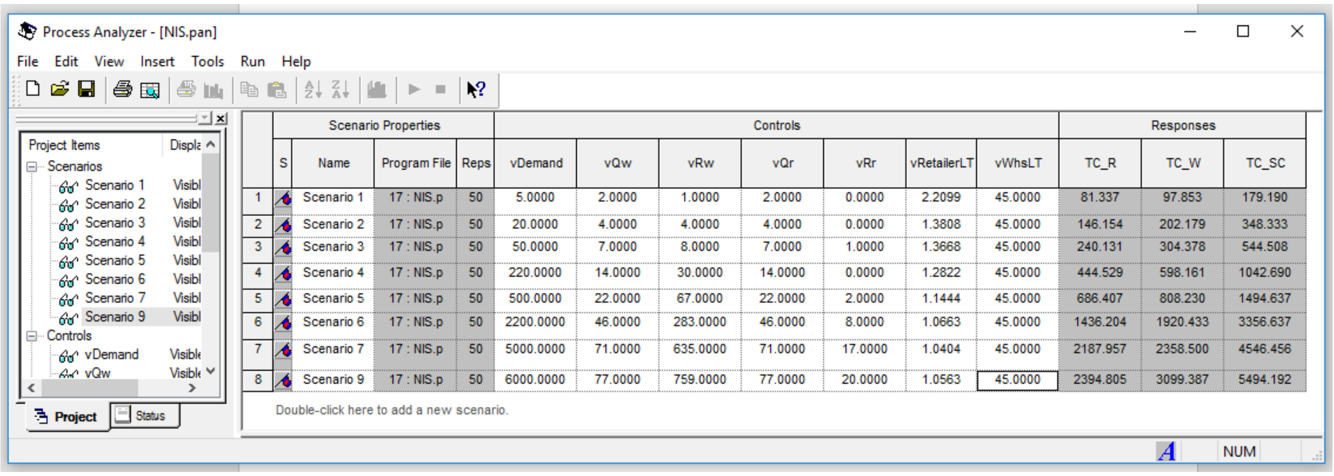


Figure 50: NIS – Validation



	S	Name	Program File	Reps	vDemand	vQw	vRw	vQr	vRr	vRetailerLT	vWhsLT	TC_R	TC_W	TC_SC
1		Scenario 1	17 : NIS.p	50	5.0000	2.0000	1.0000	2.0000	0.0000	2.2099	45.0000	81.337	97.853	179.190
2		Scenario 2	17 : NIS.p	50	20.0000	4.0000	4.0000	4.0000	0.0000	1.3808	45.0000	146.154	202.179	348.333
3		Scenario 3	17 : NIS.p	50	50.0000	7.0000	8.0000	7.0000	1.0000	1.3668	45.0000	240.131	304.378	544.508
4		Scenario 4	17 : NIS.p	50	220.0000	14.0000	30.0000	14.0000	0.0000	1.2822	45.0000	444.529	598.161	1042.690
5		Scenario 5	17 : NIS.p	50	500.0000	22.0000	67.0000	22.0000	2.0000	1.1444	45.0000	686.407	808.230	1494.637
6		Scenario 6	17 : NIS.p	50	2200.0000	46.0000	283.0000	46.0000	8.0000	1.0663	45.0000	1436.204	1920.433	3356.637
7		Scenario 7	17 : NIS.p	50	5000.0000	71.0000	635.0000	71.0000	17.0000	1.0404	45.0000	2187.957	2358.500	4546.456
8		Scenario 9	17 : NIS.p	50	6000.0000	77.0000	759.0000	77.0000	20.0000	1.0563	45.0000	2394.805	3099.387	5494.192

Figure 51: NIS – Validation for 50 Reps

5.2.2 Scenario 2 – PIS

Here apart from the base scenario mentioned above, there is an additional case assumed. The customer gives in advance that his order is going to be available at a time t and he would like his order to be met by 10 days from it. This information is available in advance to both the retailer and the warehouse. This from the previous scenario has a shortened lead time and from the mathematical model explained in the Table 10. the inventory level is partially improved and backorder level is not there as the warehouse is prepared with this level of information Sharing which aids him to serve the retailer and the consumer effectively.

Retailer Input Parameters

D	lrd	LTr	Lr	θr	h	b	o
5	1	1.34196	0.342	0.0047	30	100	15

Retailer Optimum Response

Qr	CR	Z	Rr
2.236	0.769	0.736	0.055

Warehouse Input Parameters

D	lwd	LTw	Lw	θw	h	b	o
5	35	45	10	0.1370	30	100	15

Warehouse Optimum Response

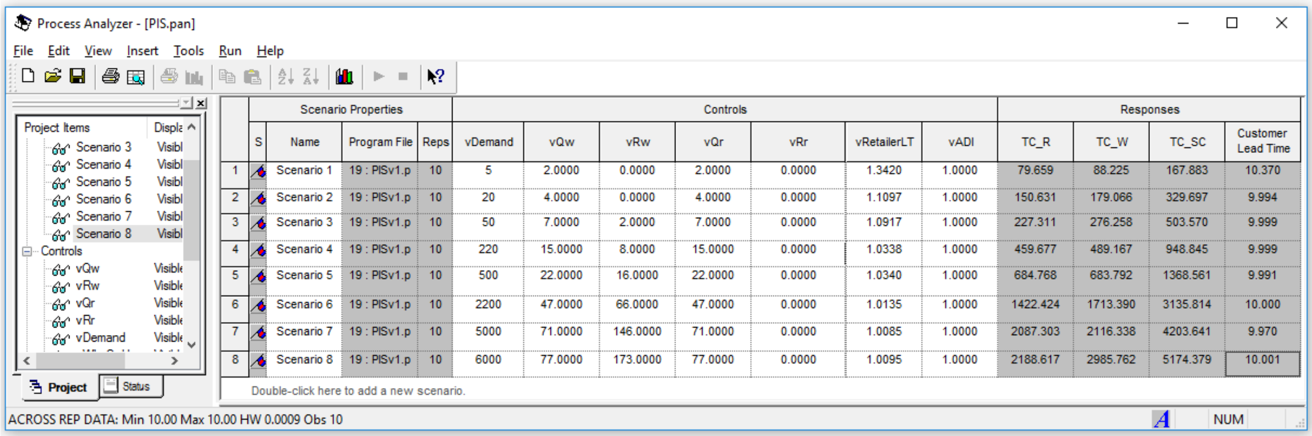
Qw	CR	Z	Rw
2.236	0.769	0.736	0.410

Total Cost Calculation of the Supply Chain for various Demand

Control						Response Expected		
D	Qw	Rw	Qr	Rr	Lr	TCr	TCw	SC_TC
5	2	0	2	0	0.3420	82.36	79.00	161.36
20	4	1	4	0	0.1097	149.82	164.34	314.16
50	7	2	7	0	0.0917	226.77	247.68	474.45
220	15	8	15	0	0.0338	459.39	521.83	981.22
500	22	16	22	0	0.0340	684.52	761.01	1445.53
2200	47	66	47	0	0.0135	1419.70	1604.48	3024.18
5000	71	146	71	0	0.0085	2132.86	2421.86	4554.72
6000	77	173	77	0	0.0095	2334.16	2617.66	4951.82

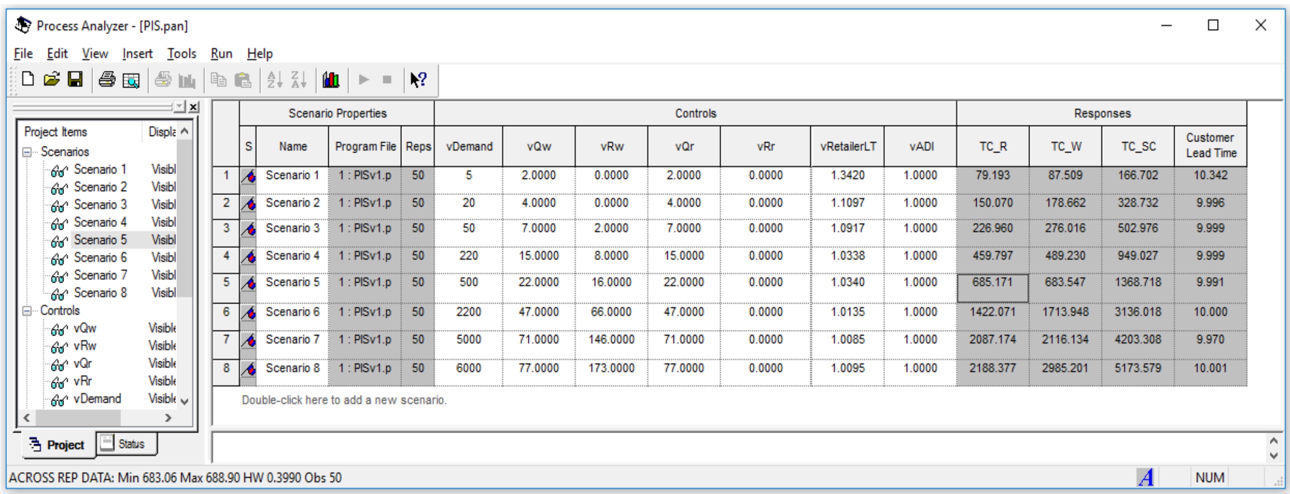
Table 10: PIS – Input and Output Parameters

With the numerical table complete, the model is fed values from it and the out put is observed. The model goes through iterations for various values until an optimized situation is reached for a demand value. Once the model is verified for a demand value as per the mathematical sheet then for various values it is run in the Process Analyser tool in Arena. Figure 52 shows the Process Analyzer output for the demand values provided to the model. The response is found to be close to the mathematical calculations. One additional output compared to the NIS is the customer lead time response. As shown in the figure 52 it is averaging to 10 days as expected by the customer and it does not vary between the min and max values. This result confirms to us that the requirement of meeting the due date of the customer is met.



	Name	Program File	Reps	vDemand	vQw	vRw	vQr	vRr	vRetailerLT	vADI	TC_R	TC_W	TC_SC	Customer Lead Time
1	Scenario 1	19 : PISv1.p	10	5	2.0000	0.0000	2.0000	0.0000	1.3420	1.0000	79.659	88.225	167.883	10.370
2	Scenario 2	19 : PISv1.p	10	20	4.0000	0.0000	4.0000	0.0000	1.1097	1.0000	150.631	179.066	329.697	9.994
3	Scenario 3	19 : PISv1.p	10	50	7.0000	2.0000	7.0000	0.0000	1.0917	1.0000	227.311	276.258	503.570	9.999
4	Scenario 4	19 : PISv1.p	10	220	15.0000	8.0000	15.0000	0.0000	1.0338	1.0000	459.677	489.167	948.845	9.999
5	Scenario 5	19 : PISv1.p	10	500	22.0000	16.0000	22.0000	0.0000	1.0340	1.0000	684.768	683.792	1368.561	9.991
6	Scenario 6	19 : PISv1.p	10	2200	47.0000	66.0000	47.0000	0.0000	1.0135	1.0000	1422.424	1713.390	3135.814	10.000
7	Scenario 7	19 : PISv1.p	10	5000	71.0000	146.0000	71.0000	0.0000	1.0085	1.0000	2087.303	2116.338	4203.641	9.970
8	Scenario 8	19 : PISv1.p	10	6000	77.0000	173.0000	77.0000	0.0000	1.0095	1.0000	2188.617	2985.762	5174.379	10.001

Figure 52: PIS – Validation



	Name	Program File	Reps	vDemand	vQw	vRw	vQr	vRr	vRetailerLT	vADI	TC_R	TC_W	TC_SC	Customer Lead Time
1	Scenario 1	1 : PISv1.p	50	5	2.0000	0.0000	2.0000	0.0000	1.3420	1.0000	79.193	87.509	166.702	10.342
2	Scenario 2	1 : PISv1.p	50	20	4.0000	0.0000	4.0000	0.0000	1.1097	1.0000	150.070	178.662	328.732	9.996
3	Scenario 3	1 : PISv1.p	50	50	7.0000	2.0000	7.0000	0.0000	1.0917	1.0000	226.960	276.016	502.976	9.999
4	Scenario 4	1 : PISv1.p	50	220	15.0000	8.0000	15.0000	0.0000	1.0338	1.0000	459.797	489.230	949.027	9.999
5	Scenario 5	1 : PISv1.p	50	500	22.0000	16.0000	22.0000	0.0000	1.0340	1.0000	685.171	683.547	1368.718	9.991
6	Scenario 6	1 : PISv1.p	50	2200	47.0000	66.0000	47.0000	0.0000	1.0135	1.0000	1422.071	1713.948	3136.018	10.000
7	Scenario 7	1 : PISv1.p	50	5000	71.0000	146.0000	71.0000	0.0000	1.0085	1.0000	2087.174	2116.134	4203.308	9.970
8	Scenario 8	1 : PISv1.p	50	6000	77.0000	173.0000	77.0000	0.0000	1.0095	1.0000	2188.377	2985.201	5173.579	10.001

Figure 53: PIS – Validation for 50 Reps

5.2.3 Scenario 3 – FIS

In the complete information sharing, with respect to the numerical the retailer has no storage hence apart from providing the demand information to the warehouse it does not carry out any processing. As the two-stage system becomes a single stage the value assumptions hold good for the warehouse and for the retailer only the profit functions exist. Table 11 gives the mathematical evaluation in the excel sheet as in a single stage system.

Warehouse Input Parameters

D	LTw	θw	h	b	o
5	45	0.6164	30	100	15

Warehouse Optimum Response

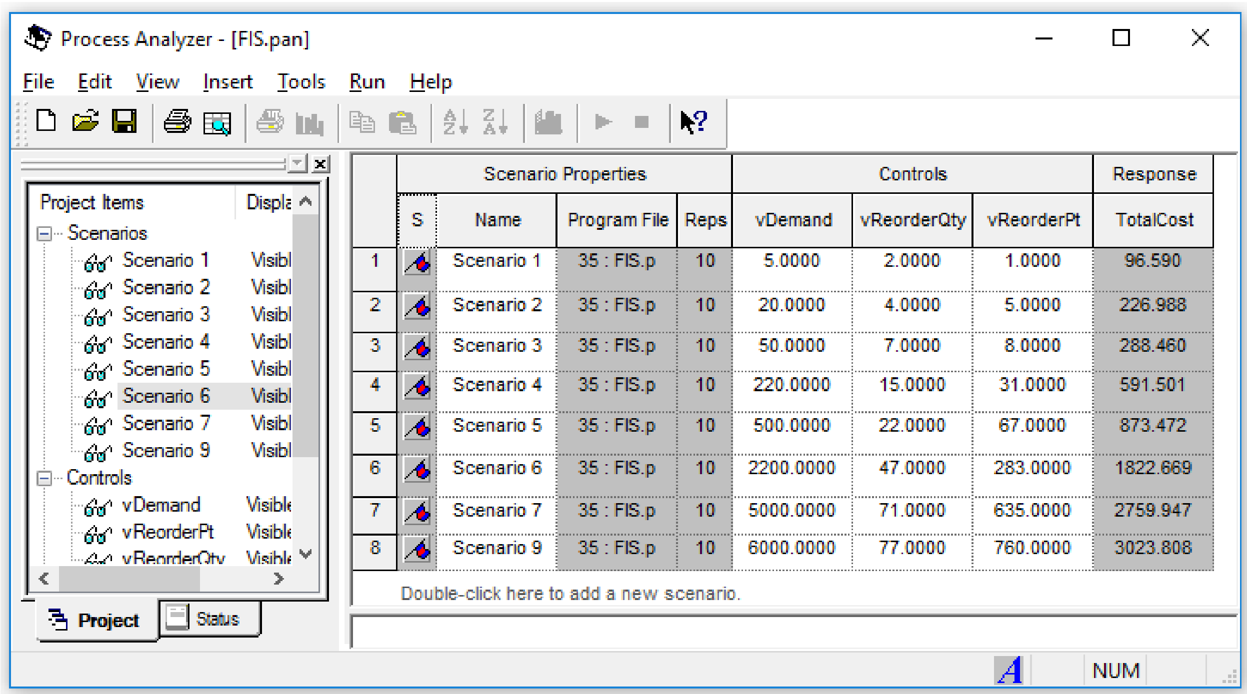
Qw	CR	Z	Rw
2.2	0.769	0.736	1.2

Total Cost Calculation of the Supply Chain for various Demand

Control					Response Expected		
D	Qw	Rw	Qr	Rr	TCr	TCw	SC_TC
5	2	1	-	-	0	96.161	96.161
20	4	5	-	-	0	226.855	226.86
50	7	8	-	-	0	288.743	288.74
220	15	31	-	-	0	590.705	590.71
500	22	67	-	-	0	872.317	872.32
2200	47	283	-	-	0	1825.967	1826
5000	71	635	-	-	0	2765.169	2765.2
6000	77	760	-	-	1	3061.849	3062.8

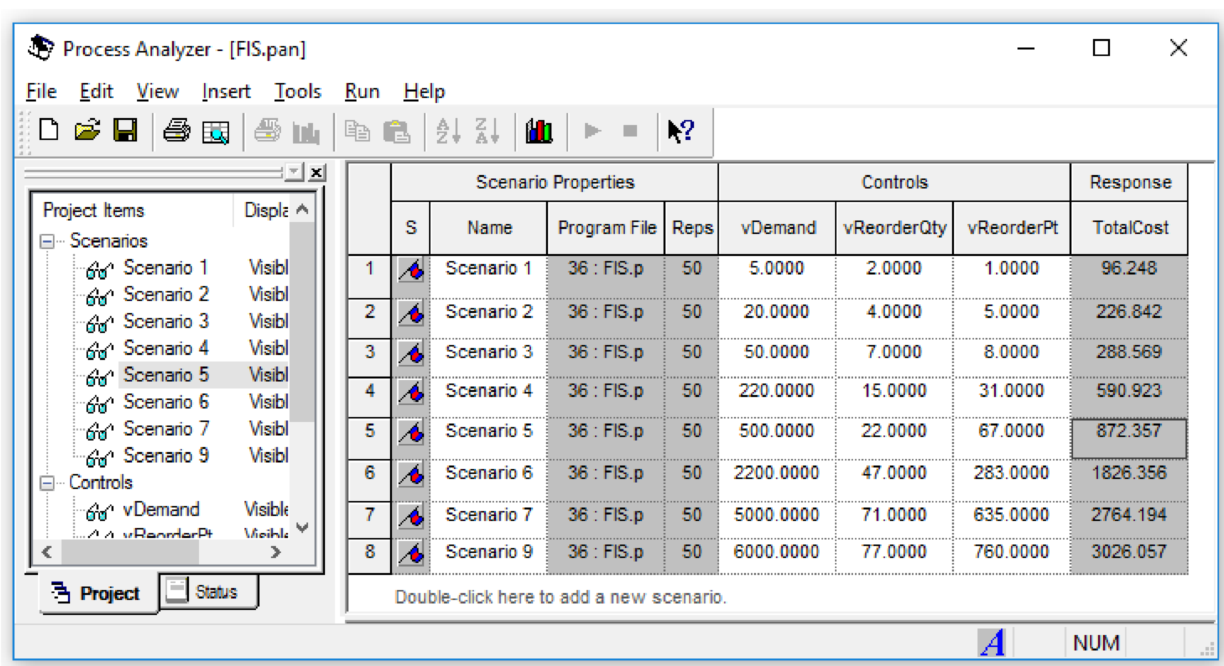
Table 11: FIS – Input and Output Parameters

As seen from the mathematical model computed, the retailer part does not exist, the warehouse does the complete processing and the values are observed for it. Feeding these inputs to the model and after repeated execution the model is verified against the model and then it is validated across various values of demand via the Process Analyzer tool and the Figure 54 depicts these outputs for the controls set for it.



	Scenario Properties				Controls			Response
	S	Name	Program File	Reps	vDemand	vReorderQty	vReorderPt	TotalCost
1		Scenario 1	35 : FIS.p	10	5.0000	2.0000	1.0000	96.590
2		Scenario 2	35 : FIS.p	10	20.0000	4.0000	5.0000	226.988
3		Scenario 3	35 : FIS.p	10	50.0000	7.0000	8.0000	288.460
4		Scenario 4	35 : FIS.p	10	220.0000	15.0000	31.0000	591.501
5		Scenario 5	35 : FIS.p	10	500.0000	22.0000	67.0000	873.472
6		Scenario 6	35 : FIS.p	10	2200.0000	47.0000	283.0000	1822.669
7		Scenario 7	35 : FIS.p	10	5000.0000	71.0000	635.0000	2759.947
8		Scenario 9	35 : FIS.p	10	6000.0000	77.0000	760.0000	3023.808

Figure 54: FIS Validation



	Scenario Properties				Controls			Response
	S	Name	Program File	Reps	vDemand	vReorderQty	vReorderPt	TotalCost
1		Scenario 1	36 : FIS.p	50	5.0000	2.0000	1.0000	96.248
2		Scenario 2	36 : FIS.p	50	20.0000	4.0000	5.0000	226.842
3		Scenario 3	36 : FIS.p	50	50.0000	7.0000	8.0000	288.569
4		Scenario 4	36 : FIS.p	50	220.0000	15.0000	31.0000	590.923
5		Scenario 5	36 : FIS.p	50	500.0000	22.0000	67.0000	872.357
6		Scenario 6	36 : FIS.p	50	2200.0000	47.0000	283.0000	1826.356
7		Scenario 7	36 : FIS.p	50	5000.0000	71.0000	635.0000	2764.194
8		Scenario 9	36 : FIS.p	50	6000.0000	77.0000	760.0000	3026.057

Figure 55: FIS Validation for 50 Reps

5.2.4 Sensitivity Analysis

Sensitivity Analysis is chosen as the best approach to validate the model. This checks the robustness of the model and helps us to understand on the response for different values of the control. Also executing it as a batch the various factors together aids us to conclude better on the outcome of the outputs obtained.

Now the model has been verified and validated across various collaborations for information sharing. The outputs from it are consolidated as shown in Table 12. The No information sharing system (NIS) is kept as the base and compared with the other two systems. The NIS could be the traditional system looking to transform to the partial or the full information system which are more agile versions in comparison to it.

From the table, on comparing the partial information system values to the no information sharing system an average of 7% improvement is observed and similarly if the full information Sharing is compared to the no information Sharing then there is a 40% increase overall.

Arena Simulation - Sensitivity Analysis

Demand Rate	Total Cost $			TC reduction % to NIS	
	NIS	PIS	FIS	PIS	FIS
5	180	168	97	7%	46%
20	350	330	227	6%	35%
50	546	504	288	8%	47%
220	1039	949	592	9%	43%
500	1491	1369	873	8%	41%
2200	3353	3136	1823	6%	46%
5000	4545	4204	2760	8%	39%
6000	5492	5174	3024	6%	45%
			Average	7%	43%

Table 12: Sensitivity Analysis Table

This shows that the full information Sharing is more robust compared to the partial information Sharing. Also, in Figure 56 the total cost of the supply chain is plotted against various demand values and the performance of the three level of information sharing is analyzed.

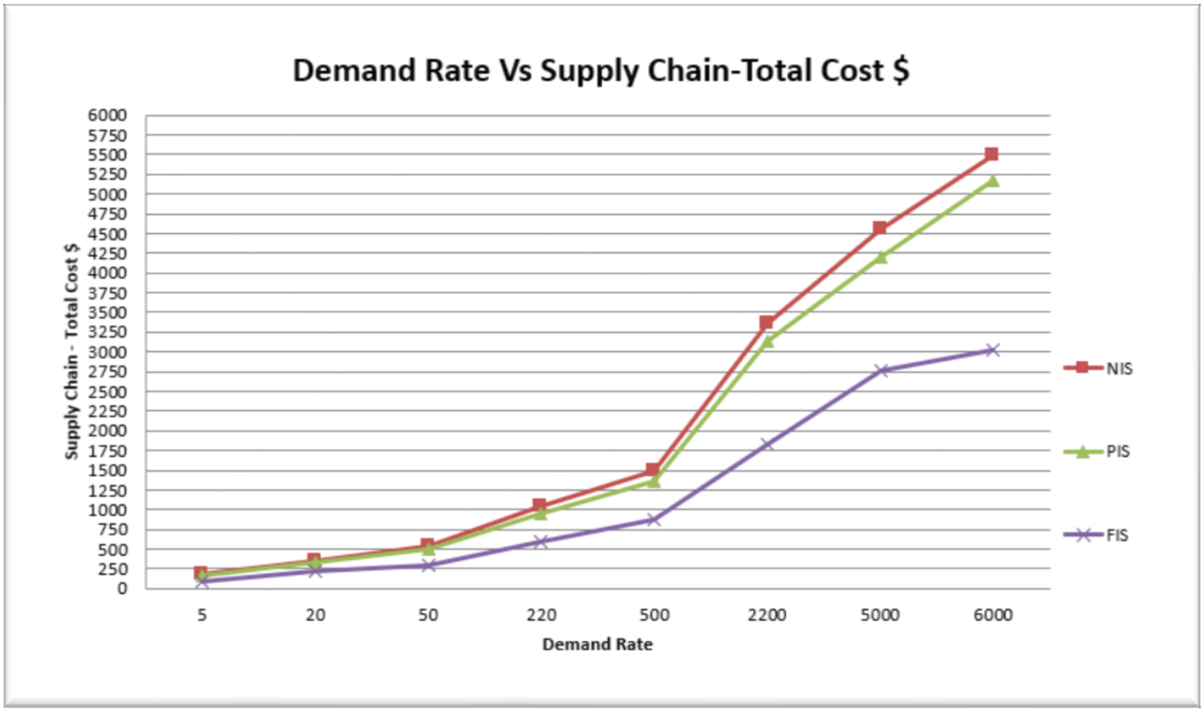


Figure 56: Demand vs Total Cost based on Information Sharing

From Figure 56, it can be seen that with no collaboration the supply chain cost is found to be highest. Followed by it is the partially shared model. Although this graph is very close to the NIS graph, there is still a 7% improvement and since the demand is checked over a range the smaller demands looks to be nearer. With respect to FIS since the retailer part is not available, a significant gap is seen. Even if the system would like to consider partially some holding cost for the retailer, still the FIS is more robust compared to other information sharing model with 43%.

CHAPTER 6:

CONCLUSIONS AND FUTURE WORKS

6.1 Conclusion

This thesis attempts to demonstrate how information sharing within the supply chain can be beneficial. A two-stage system comprising of an independent retailer and warehouse are studied for inventory management. Partial and full partnership scenarios are applied to the same two-stage system and results compared with the initial base study (no information sharing). The partial information sharing model uses an advance demand information concept by which the customer shares his order information and his due date expectation in advance. The full information sharing model on the other hand is based on the VMI concept in which there is no retailer and the entire decision of the inventory management system is with the warehouse. The three levels are modelled in Arena Simulation and the output of the models are taken for study. The comparison results show that there is a progressive improvement in the profit when moved from one level of information sharing to another. Thereby deducing that a collaborative supply chain is an efficient supply chain. Also, the simulations developed may aid traditional retailers looking to transform to an agile supply chain. It supports to experiment their supply chain transformation policy and to fine tune it as required before the actual policy is deployed for adherence.

6.2 Future Works

The proposed work can be extended in various ways as discussed below:

- A multi echelon system can be considered where in a warehouse serves multi retailers who in turn serve their customers at the end. This will involve migrating from a two-stage supply chain system to a multi-level storage supply chain system.
- The focus of the thesis was on horizontal collaboration. There is possibility to extend it to multiple hierarchies i.e. vertical collaboration within and across organizations (Barratt, 2004).
- The thesis studied unidirectional information sharing from the retailer to supplier up stream. Bidirectional information sharing can be investigated.
- The cost of information sharing can be included in the present study. The retailer and warehouse may need to pay an investment cost to have information shared in by the customer.
- Information sharing across the supply chain member may lead to data leakage or unnecessary outflow of information to partner member where it could be misused. So information security mechanisms on how this could be controlled can be considered in the future work.
- Last, but not the least the type of information sharing could be extended to more than demand.

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APPENDIX A

A1 No Information Sharing – Excel Spread sheet

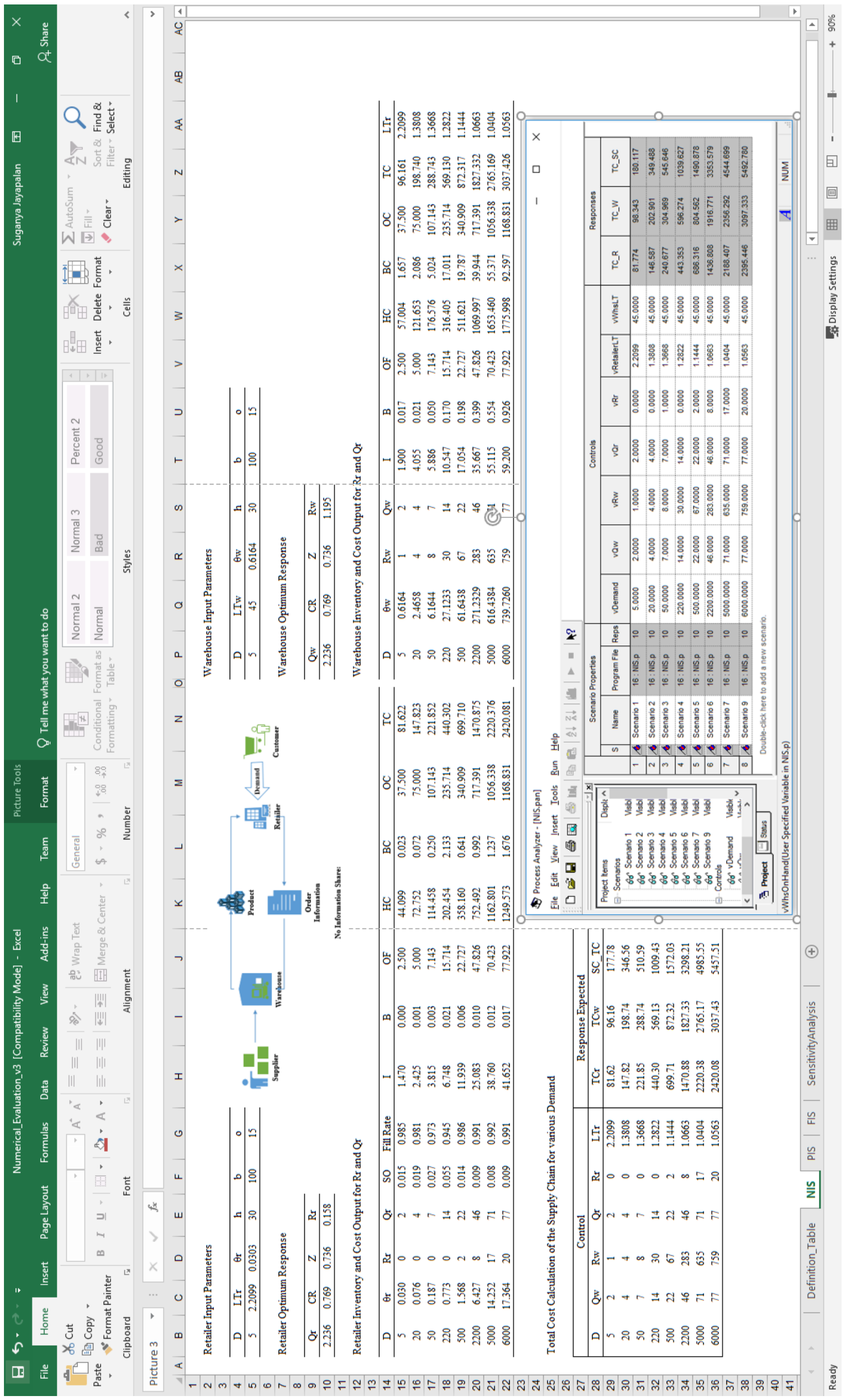

Figure A 1: No Information Sharing – Excel Spread sheet

A2 Partial Information Sharing – Excel Spread sheet

Figure A 2: Partial Information Sharing – Excel Spread sheet

A3 Full Information Sharing – Excel Spread sheet

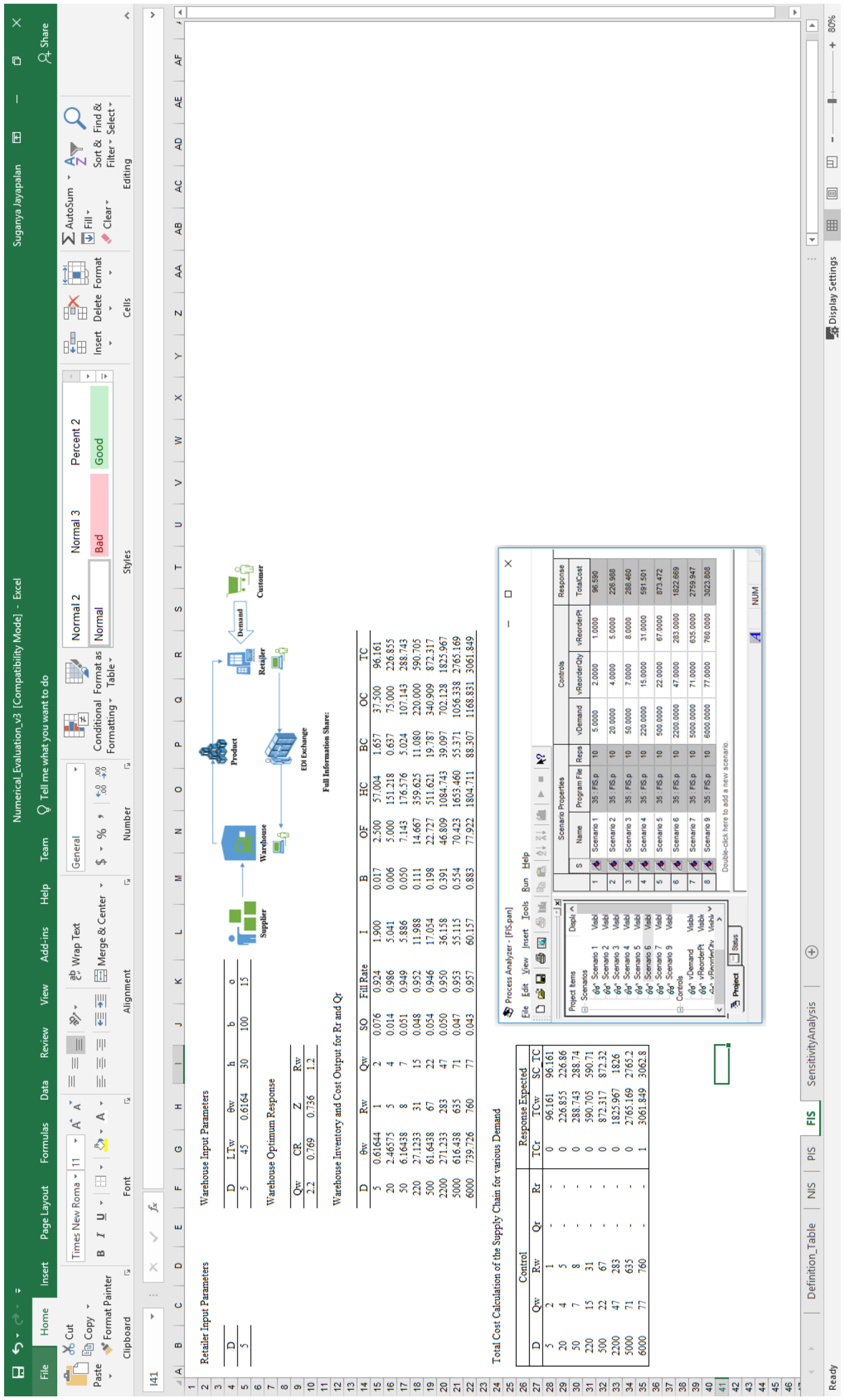

Figure A 3: Full Information Sharing – Excel Spread sheet