Original Scientific Article Journal of Decision Analytics and Intelligent Computing
Vol. 3 issue 1, (2023) 62-79 https://doi.org/10.31181/jdaic10010052023a

A simulation study of single-vendor, single and multiple-manufacturers supply chain system, with stochastic demand and two distribution policies

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Received 9 December 2022

Accepted for publication 23 April 2023

Published 10 May 2023

Abstract

This paper addresses the long-standing stochastic single-vendor, multi-manufacturer inventory control problem, using simulation optimization. It is assumed that Manufacturers producing similar goods experience very high random demand; hence, safety stock of raw materials is held in reserve in their warehouses. The vendor supplying this raw material (principal ingredients) as a policy restricts shipments to multiples of full truck load. Thus, it is necessary to take replenishment decision and coordinate delivery among these manufacturers. To solve this problem, we modeled the single vendor, single manufacturer version of the problem (AlDurgam et al., 2017) using simulation optimization techniques, which was validated numerically using parameters and results from AlDurgam et al. (2017). The simulation model was modified systematically to relax the single manufacturer assumption under two distribution policies namely, joint reorder point and vendor managed inventory. These policies were evidently modeled with stringent conditions in literature. A numerical example was provided to compare the performances of the two proposed policies, and the VMI policy was found to performed better in terms of financial savings. Lastly, we investigate the robustness of the famous continuous review (Q, R) inventory policy which is widely used in the mathematical modeling of this problem, against the common cycle assumption. The coefficient of variation is thus suggested as a judgment criterion of when to embrace simulation modeling ahead of other modeling techniques.

Keywords: Supply chain management, simulation optimization, distribution policy, vendor managed inventory (VMI), Joint reorder point (JRP)

1. Introduction

Supply chain management deals with the optimal flow of raw materials, information, finance and finished products from the vendor down to the final consumers. Many research results had demonstrated that inventory control is a viable technique for minimizing the total supply chain cost. Inventories are material in stocks and must be maintained at the possible minimum over a reasonable period of planned time. Different supply chain settings and extensions of the classical EPQ problem are available in literature, and several issues bordering on supply chain improvement had been addressed. Some of these issues include information sharing, costing, trade credit agreement, imperfect production systems, delay time, level of echelon etc. In this paper, we address the Single-Vendor, Multi-Manufacturer (SVMM) inventory control problem assuming stochastic demand. Two distribution policies (Joint re-order level and Vendor managed inventory) were considered and problems of common shipment, rigidity of equal shipment numbers by manufacturers and joint ordering were resolved. The paper is organized as follows: Section 2 summarizes literatures that are related to the SVMM problem. Section 3 defines the problem formally. Simulation optimization method and its validation as a suitable approach for the problem presented in Section 4. Two different distribution policies are proposed in section 5. Section 6 presents the summary and conclusion.

2. Literature review

Over time, the SVMM inventory control problem has been of interest to researchers. From literature, a lot of research work had been done considering different settings of the problem, this includes number of echelons, responsibilities, cost assumptions, distribution policies, etc. In this section, we present some of the relevant work categorized under deterministic and stochastic models.

2.1. Deterministic Models

Bylka (1999) studied a Single-Vendor, Multi-Buyers (SVMB) problem where vendor production is in batches and delivery is made to multiple-buyers, whose demands follow a periodic pattern. The problem was formulated and solved using deterministic dynamic programming model. Woo et al. (2001), studied a SVMB integrated inventory problem, when all participants have a common goal of reducing the joint total cost, through a combined investment that is focussed ordering cost reduction. The authors developed a model that determines both the optimal investment and replenishment decisions.

Yang and Wee (2002) incorporated deteriorating items into SVMB integrated inventory problem. The study explained the possible benefit of the proposed policy, over autonomous decisions made by the vendor and buyers. Banerjee and Burton (2004) investigated the impact of ordering cost in (SVMM) problem. Joint and independent ordering policies were compared. The result however showed that the joint ordering policy performed better in terms of average total cost. Chan and Kingsman (2007) extended the SVMB integrated inventory problem by coordinating both delivery time and the production cycles in a supply chain system. The authors showed that the coordinated model gives better result than independent optimisation. Chu end Leon (2008) considered confidentiality of information in the coordination SVMB supply chain system. The aim is to minimize all inventory related costs in the supply chain system. Two nested powers of two replenishment policies were considered i.e. separate and simultaneous replenishment policies. Hoque (2008) extended SVMB supply chain problem by considering the impact of batch size. Their model showed that unequal batch shipment gives better result than equal batch shipments. Abdul-Jabar et. al (2008) proposed a model that determines the order quantity of the buyers, production and shipment schedule of the vendor such that the total supply chain cost is minimised. Zavanella and Zanoni (2009) considered SVMB supply chain system under consignment stock agreement. The vendor managed the inventory in the buyers' warehouses by coordinating delivery to lessen the integrated total cost. The result of the study showed that the jointly managed inventory system gives more savings in terms of cost than the independent policy which is dependent more on the coordination approach used by vendor.

Darwish and Odah (2010) like Zavanella and Zanoni (2009) studied the effect of capacity constraint under vendor managed inventory (VMI) policy in SVMR supply chain system. Chan et al. (2010) showed that the synchronisation of the delay payment with ordering and production cycles gives better savings in terms of cost than independent optimisation. Hoque (2011) relaxed some assumptions of Hoque (2008) by coordinating production flow such that equal, unequal, and mixed lot size can be distributed to different buyers. Other assumptions considered are limited capacities of the transport facility, finite lead time and buyers' storage space. Chan and Lee (2012) proposed a model that jointly considered the benefit of incentive policy through a price discount to the buyer and coordination through synchronization of ordering and production cycle in SVMB supply chain. Ben-Daya et al. (2013) showed that for SVMB supply chain system, both VMI and Consignment stock agreement offer better reward when the vendor's capacity is flexible, vendor set up cost is low, and buyers have significant ordering cost. Glock and Kim (2014) considered a returnable transport item like crate in a SVMR supply chain system. The authors proposed two delivery strategy under early delivery and late delivery strategy. Fauza et al. (2016) considered different quality characteristics in SVMB food supply chain as against the instantaneous depletion of stocked item over time due to direct decomposition in literature. The authors represented the quality degradation of the vendor raw material using kinetic model and a shelf-life pricing policy was adopted to represent the value degradation of finished goods. The proposed model gives better saving than the bench marked model. Remanufacturing in SVMB supply chain was considered by Ben-Daya et. al (2019) under a centralised consignment stock policy. The percentage of returned items and holding cost were suggested as key parameters affecting the production lot sizing and the shipping policy to buyers. Tarhini et al. (2020) showed that collaboration between buyers through transhipment for a SVMB supply chain system where the vendor takes the lead and operates consignment stock agreement can reduce both costs incur by the buyers and vendors.

These papers however considered different multi echelon supply chain problems, neglecting the stochastic nature of most demand.

2.2. Stochastic Models

If compared with the SVMB deterministic demand models, the stochastic demand SVMB integrated supply chain problem has received lesser attention. Kim et al. (2005) modeled both centralized and decentralized policy for Single vendor, Multi-Retailers (SVMR) inventory control problem under non-stationary demand situation. The objective is to realise a predetermined service level fixed for different retailers through the safety stock and lead time. A simulation model was developed and tested for both stationary and non-stationary demand conditions. The outcomes suggested that the centralized policy is more stable and produces comparatively better result. Taleizadeh et al. (2012) studied multiple items in a SVMB inventory problem. The authors described the variable lead-time as a linear function of the lot size, buyers' budget constraint for purchase, and a shortage cost that comprises of both backorder and lost sales. A Mixed integer linear programming model was developed and solved using some metaheuristics optimization techniques.

Jha and Shanker (2013) proposed an integrated model for SVMB supply chain problem where items manufactured in batches are supplied to some buyers. Each buyers uses the Q, R inventory policy and all shortages from the buyers are backordered. The proposed mathematical model however forces the buyers to place the same numbers of orders within the same production cycle, and replenishment of stocks to buyers are done jointly in a common shipment at different lead time. Rad et al. (2014) considered two buyers who received the same item from the same vendor that produces at finite production rate, under VMI and returnable transport items (RTI) policies. Comparison via simulation showed that VMI gives better savings in terms of supply chain cost, and it offers deeper insight on the selection of the optimal inventory policies which is directed at improving the supply chain performances. The impact of variable production rate on product quality and supply chain cost for a SVMB supply chain under a single set-up, shared and multiple delivery policy was considered by Sarkar et al. (2018). The authors assumed equal numbers of shipment for all buyers from the vendor through a controllable lead time. Chan et al. (2018) showed that the synchronization of the buyers ordering cycle length and vendor production cycle length gives better result than both decentralised policy and common cycle policy when stock out condition permitted under stochastic demand. Aritonang et al. (2020) proposed a mathematical model that minimizes the total cost for a SVMB supply chain system, where each vendor shipment is shared between multiple buyers that are experiencing stochastic demand in sales and have adjustable lead time that ensures all buyers receive equal numbers of delivery shipments. Vandana and Sana (2020) introduced ameliorating items like livestock, and the accumulated inventory is assumed to depend on the procreation and deterioration (birth) rate. Castellano et al. (2020) considered back ordering and lost sales mixture together with controllable lead time through a periodic review policy. The authors assumed both deterministic demand at the initial moment and stochastic demand later to portray the incompleteness of information about most demand distribution.

Therefore, it can be concluded from the aforementioned research work that little, or no work has been done on independent shipment delivery and raw material replenishment coordination among multiple manufacturers/buyers facing stochastic demand for their products. Most times, manufacturers' demands are independent, and the material requirement for their final product differs thus the number of orders required by each manufacturer for production should be independent and not the same as mostly observed in mathematical modelling of this problem. Also, distribution of stocks to manufacturers' warehouses should be done separately by the vendor, at different lead time which is regulated in literature through a crashing process at an extra cost that is incurred by some manufacturers who received shipment earlier than anticipated thereby increasing the holding cost further. This research takes into consideration this independent delivery and the objective is to minimize the overall cost incurred by this supply chain system in a stochastic demand environment. A detailed description of the simulation study performed to address this problem is provided in Section 3.

3. Problem definition and assumptions

Consider a raw material producer (vendor) who produces this material in a single run and supplies different manufacturers with the same material as principal ingredients for their finished products. As a policy the vendor makes raw material delivery in multiples of full truck load shipments separately to the manufacturers and it is assumed that all manufacturers' products are subjected to very high random demands, which are independent of one another; therefore, stocks of raw materials are kept as inventories. Each manufacturer starts production immediately the first shipment is received from the vendor, and the ingredient is consumed at a rate that is relative to each manufacturer's production rate. For traceability and like AlDurgam et al. (2017) the following assumptions are made:

- -The production rate of the vendor is deterministic and fixed. Delivery to manufacturers is in multiples of full truckloads.
- -The vendor production rate is greater than the inventory consumption rate of all manufacturers.
- -The rate at which a manufacturer consumes raw material is directly related to his production rate.
- -All shortages are backordered
- -Time-homogeneous and normally distributed demand.

4. An insight on the single vendor, single manufacturer (SVSM) version of the problem and validation of the single vendor, multi-manufacturer simulation models

To validate and develop a simulation model for the problem described in Section 3, Figure 1 shows the SVSM version of the problem (AlDurgam et al., 2017).

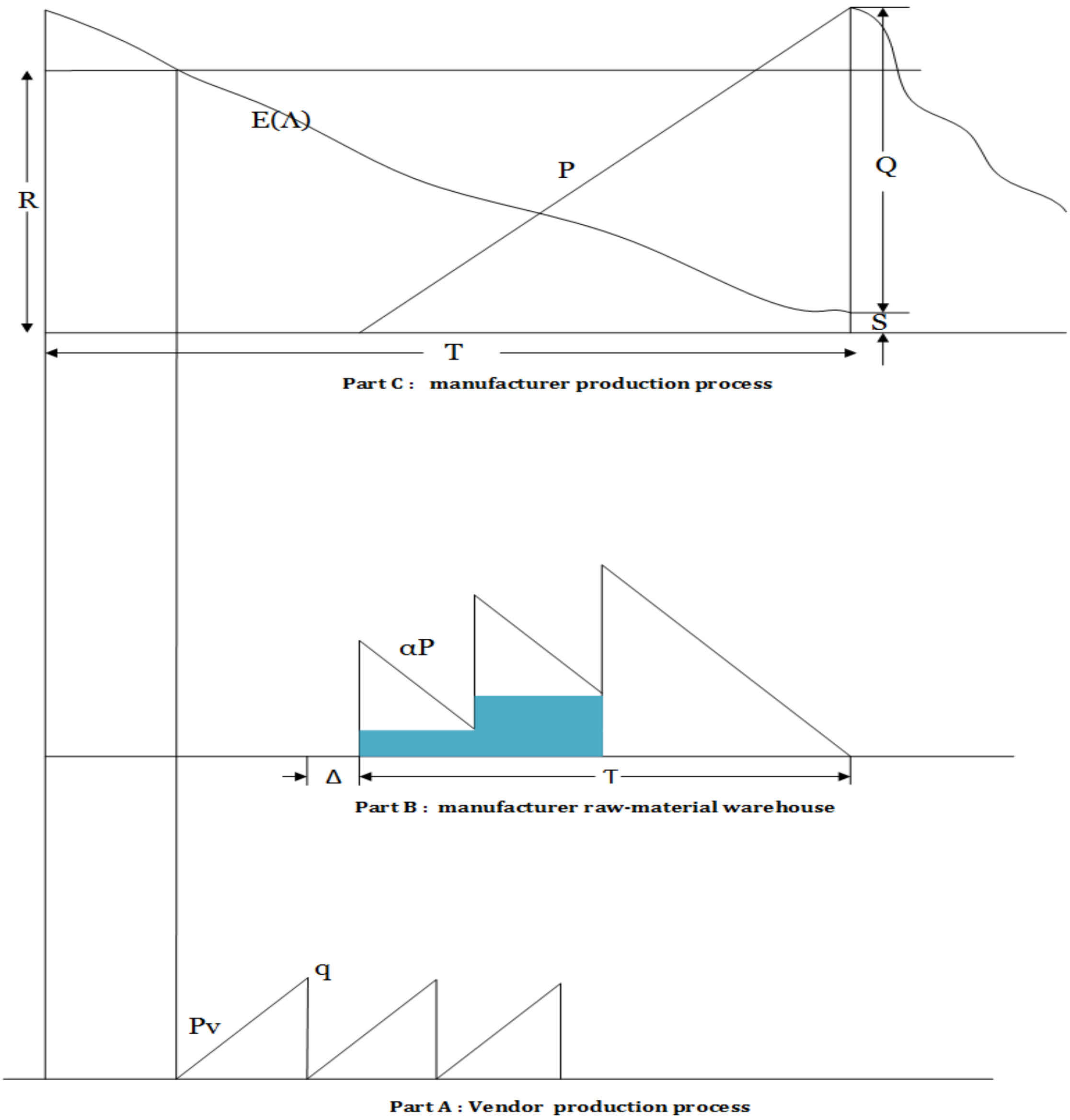

Figure 1. The SVSM profile (Aldurgam et.al, 2017)

We addressed the same problem using discrete event simulation optimization. Arena simulation software 15.0 and Opt Quest optimization package were used, and the results of both optimization techniques (analytical and simulation) were compared for validation of the simulation model (Ignall et al., 1978). AlDurgam et al. (2017) utilizes the popular continuous review inventory policy and the objective was to determine the reorder level, economic manufacturing quantity of the manufacturer, numbers of full trucks shipments from the vendor and best production rate that minimizes the overall cost function of the supply chain as presented in the formulation below.

$$T.C_s(Q,n,P,R) = \frac{E[\Lambda]}{Q}[A_s + [nA_r + z] + A_m] + \frac{E[\Lambda]\alpha^2 Q}{2nP_v}h_v + \alpha E[\Lambda][C + X] + \frac{Q\alpha E[\Lambda]}{2nP}\left[n\left[1-\frac{\alpha P}{P_v}\right] + \frac{\alpha P}{P_v}\right]h_r + h_m\left[\frac{Q}{2}\left[1-\frac{E[\Lambda]}{P}\right] + R - E[\Lambda]\left[\frac{\alpha Q}{nP_v} + \Delta\right]\right] + \frac{\pi E[\Lambda]}{Q}\int_R^{\infty}[Y-R]f[y]dy + E[\Lambda]\left(\frac{g}{P} + bP^B\right) \quad (1)$$

Subject to

$$\frac{nq}{\alpha Q} = 1 \quad (2)$$

$$n \leq \frac{P_v I_{max} - \alpha q P}{q(1-\alpha P)}, n \in Integers \text{ (Aldurgam et. al, 2017)} \quad (3)$$

The conceptual model for the SVSM simulation model is shown in Figure 2.

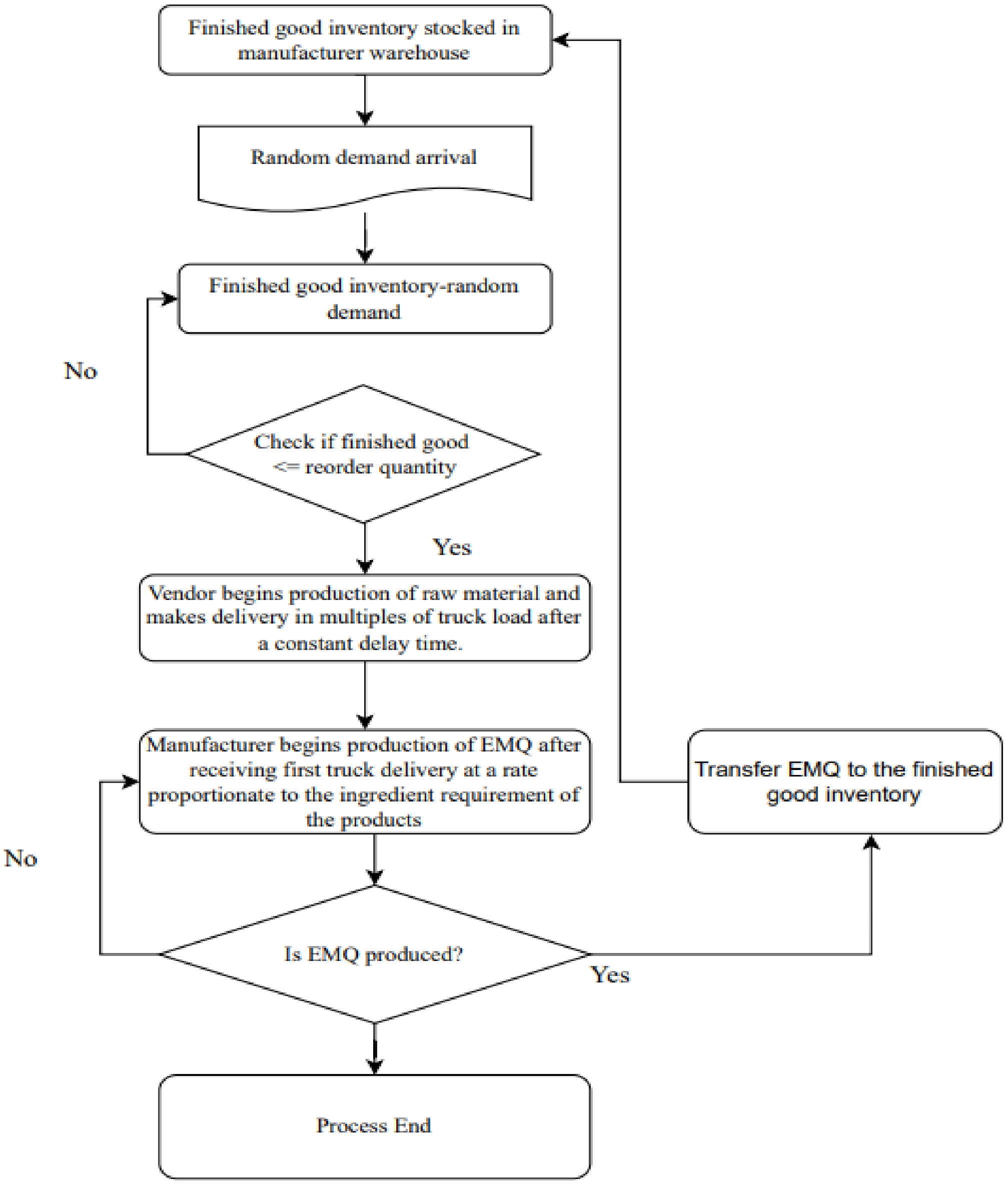

Figure 2. Conceptual simulation model for the SVSM supply chain problem

The model which was developed to mimic the inventory profile described in Figure 1 was run over an infinite horizon with the simulation clock set at fifty (50) years, and each run is replicated fifty (50) times. A steady state was reached after a warm period of nine (9) months using the output analyser software, which was cut off prior to recording data from the simulation. Statistics gathered from the simulation model is presented in Table 1. The objective of the simulation model is to minimize the long run average total cost of the supply chain system subject to the full truck load assumption, and like AlDurgam et al. (2017), the decision variables considered are manufacturer reorder level and the economic lot size produced, optimal production rate and the number of shipments sent by the vendor. Arena flowchart module describing the supply chain in figure 1 is presented in Figure 3.

Table 1: Statistics gathered from the simulation model

Statistics	Type
Vendor set up cost	Output
Vendor holding cost	Time persistent
Vendor acquisition cost	Output
Manufacturer holding cost for finished good available for demand sales	Time persistent
Shortage cost	Time persistent
Manufacturer holding cost for finished goods in production	Time persistent
Raw material holding cost in manufacturers warehouse	Time persistent
Production cost of raw material	Output
Manufacturer Set up cost and transportation cost	Output
Raw material ordering cost	Output
Raw material acquisition and production cost by the manufacturer	Output
Long run average total cost	Output

The simulation model was run using parameters presented in Table 2 from AlDurgam et al. (2017), customer demand is made deterministic (standard deviation set at 0.001). The result obtained is presented in Table 3, and this validates the SVSM simulation model, based on the percentage difference in total cost which was less than 1%.

Table 2. SVSM Model Data

Model parameter	Parameter value
Expected demand / unit time	140
Demand standard deviation/ unit time	20
Manufacturer set up / cycle	2500
Vendor set up cost /cycle	2000
cost of transporting raw material/ full truck	500
Vendor holding cost / item / unit time	3
Manufacturer raw material holding cost/item/unit time	1
Manufacturer holding cost in the finished goods inventory/ item /unit time	5
Constant delay lead time for full truck loading, offloading and transportation	1
Fixed shortage cost per unit short	200
Raw material production cost of vendor/ unit	1.5
Acquisition cost of manufacturer/ unit	3.5
Consumption rate to production rate ratio for the raw material	2
Cost of operating time/ unit time	2000
Exponent component in manufacturer production cost function	1
Multiplier component in manufacturer production cost function	0.065
Ordering cost/ unit time	1000
Vendor production rate/ unit time	800

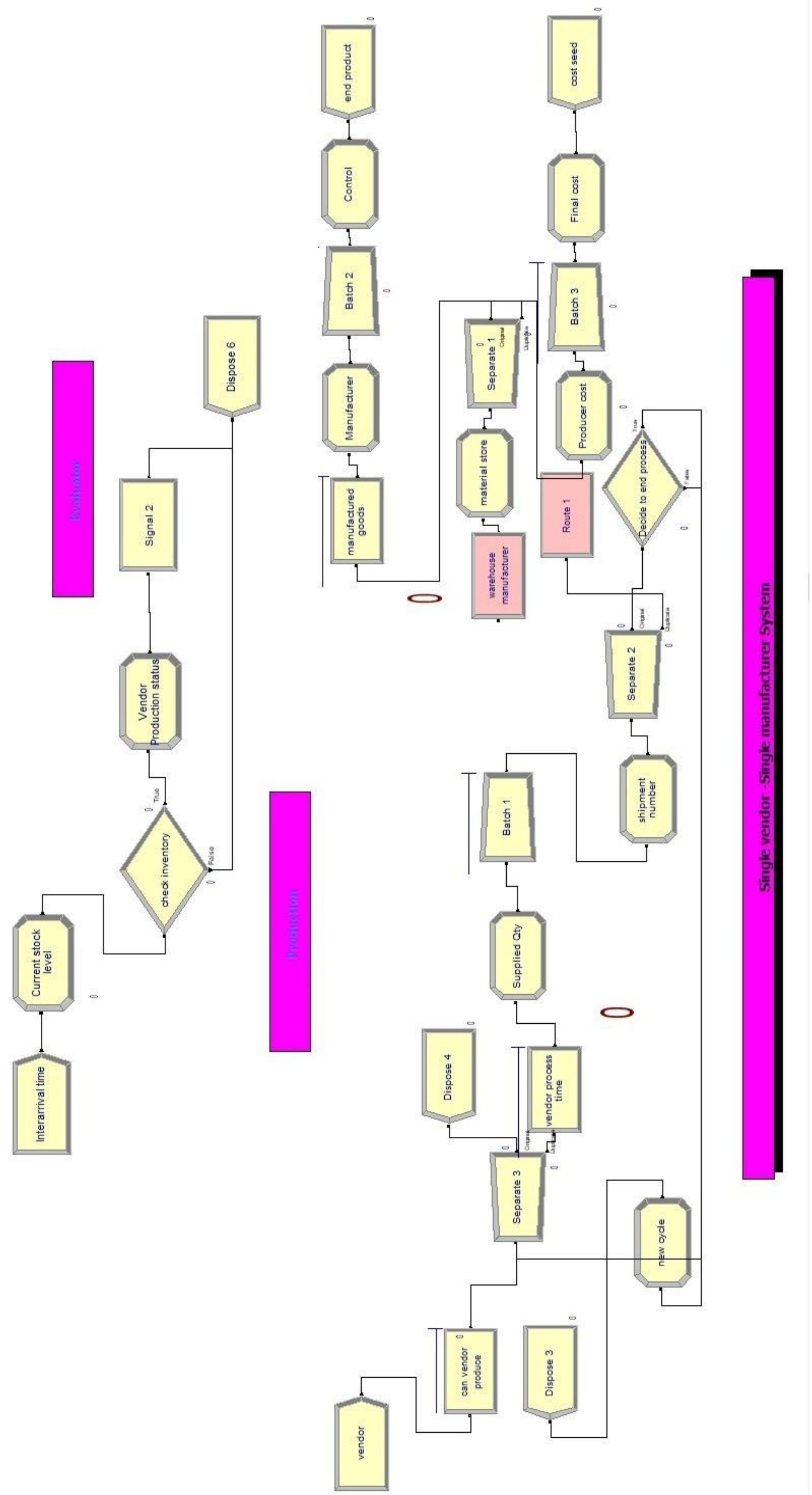

Figure 3. Arena flowchart module describing the SVSM integrated model

Furthermore, the robustness of the continuous review (Q, R) policy, which is mostly used in modelling of multi-echelon supply chain with random demands is evaluated using the validated discrete event simulation model. The Continuous review (Q, R) policy assumed existence of a renewal point, through the expected backorder per cycle, which is approximated as zero (Wensing, 2011). For this investigation, we varied the demand standard deviation, and values from 20 to 80 in steps of 20 were used.

Table 3. Analytical vs. simulation optimization sol

Optimization method	Optimal lot size	Optimal number of trucks	Production rate Of the manufacturer	Reorder point	Total cost
Analytical	9600	6	396	9357.4	61601.5
Simulation	9600	6	396	9357.54	61927.9

The results from both models (analytical and simulation) are presented in Table 4, 5, 6, 7 and 8.

Table 4. Analytical versus simulation model results at $S.D = 0.01$

Expected demand	Avg.Total.Cost (Analytical)	Avg.Total.Cost (Simulation)	(%) Difference
80	9610.6	9568.31	0.4
120	12324	12237.73	0.7
160	15252.67	15180.31	0.5
200	23821.09	23766.30	0.2
240	26995.30	26833.33	0.6
280	36925.00	36758.83	0.5
320	61947.92	61731.10	0.4

Table 5. Analytical versus simulation model results at $S.D = 20$

Expected demand	Avg.Total.Cost (Analytical)	Avg.Total.Cost (Simulation)	(%) Difference
80	9764.91	9515.96	2.6
120	12863.02	12648.21	1.7
160	15737.25	15548.40	1.2
200	24280.24	24010.92	1.1
240	27529.61	27281.84	0.9
280	37309	36861.29	1.2
320	62376.93	61815.53	0.9

Table 6. Analytical versus simulation model results at $S.D = 40$

Expected demand	Avg.Total.Cost (Analytical)	Avg.Total.Cost (Simulation)	(%) Difference
80	10110.7	9636.10	4.9
120	13100.53	12688.95	3.2
160	16021.70	15636.35	2.5
200	24519.57	23996.17	2.2
240	27774.30	27274.71	1.8
280	37595.01	36828.49	2.1
320	62386.06	61436.98	1.6

Table 7. Analytical versus simulation model results at $S.D = 60$

Expected demand	Avg.Total.Cost (Analytical)	Avg.Total.Cost (Simulation)	(%) Difference
80	10456.50	9808.20	6.2
120	13336.92	12696.74	4.8
160	16453.04	15811.37	3.9
200	24866.80	24071.06	3.2
240	28284.25	27322.34	3.4
280	37990.00	37116.23	2.3
320	62725.00	61470.50	2.0

Table 8. Analytical versus simulation model results at $S.D = 80$

Expected demand	Avg.Total.Cost (Analytical)	Avg.Total.Cost (Simulation)	(%) Difference
80	10701.41	9706.18	9.3
120	13872.11	12998.17	6.3
160	16854.91	15911.04	5.6
200	25338.22	24248.68	4.3
240	28706.39	27213.66	5.2
280	38388.47	39616.90	3.2
320	62877.31	61431.13	2.3

Furthermore, a graphical representation of these results is presented in Figure 4.

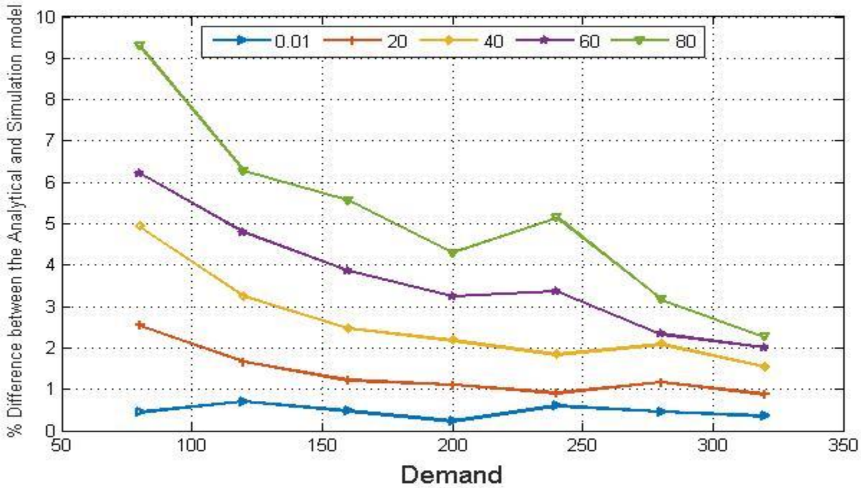

Figure 4. Percentage difference in the average total cost of both analytical, and simulation model, for different values of demand standard deviation (0.01, 20, 40, 60, 80) using the SVSM version of the problem

As observed from the graph, when the standard deviation (σ) is 0.01, both models seem deterministic, and the percentage difference in the average total cost obtained from both models (analytical and simulation) is less than 1%, for different levels of demand tested. However, as standard deviation (σ) increases, the percentage difference in the average total cost increases. The coefficient of variation (σ/μ) which rises with the standard deviation is therefore suggested as a judgement criterion of when to use simulation as a modelling technique i.e., simulation modelling can be more appropriate when coefficient of variation (σ/μ) is greater than or equal to 1.

5. Sensitivity analysis / experimentation

In this section, we investigate how the simulation model respond to changes in key parameters. The Opt Quest optimization software in Arena 15.0 was used and each parameters studied were varied independently.

5.1. Expected demand rate effect

Figure 5 explains how the simulation model responds to changes or increase in the average value of manufacturers demand rate i.e an increase in the expected demand rate of the manufacturer will cause the manufacturer to order more truckloads of raw material together with a regular increase in his re-order level and rate of production. This impacts the supply chain cost directly as it grows as demand increases. It is however worthy of note that due to the full truck load delivery assumption; the numbers of full truck (n) and manufactured lot size (Q) do not increase linearly.

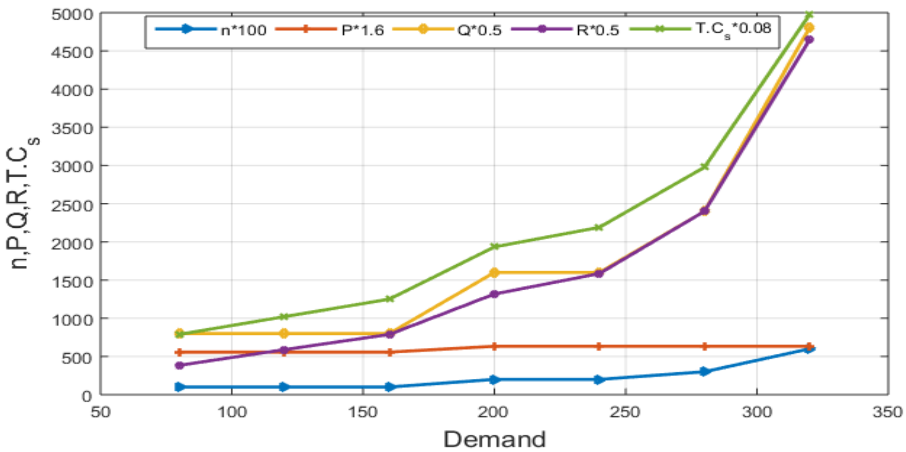

Figure 5. Effect of manufacturer's product expected demand

5.2. Effect of variation in demand

Another parameter studied is demand variability, and its effect is illustrated in Figure 6. When variability is high, the manufacturers stock more product to avoid shortages or lost sales i.e., the manufacturer increases the re-order level to produce more finished product in time. However, the model shows that by increasing the rate of production, the supply chain cost is kept low.

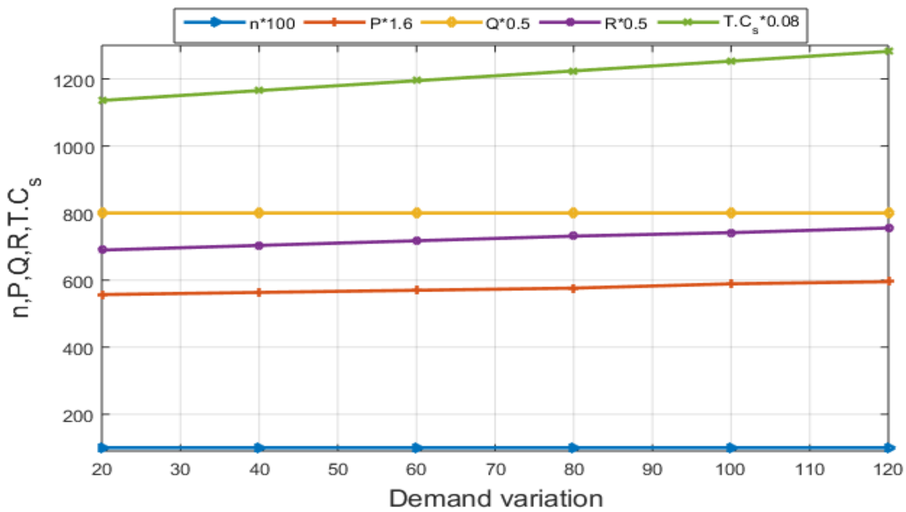

Figure 6. Effect of demand variability (σ)

5.3. Holding cost effect in the manufacturer warehouse

The effect of the holding cost in the manufacturer inventory is shown in Figure 7. Increasing the holding cost in the manufacturer warehouse give rise to a drop in the re-order level. This ensured that the cost incurred in holding both the raw material and end products in the manufacturer warehouse is lessened. However, to avoid shortages the production rate rises and as an effect result in an increment in the cost of the supply chain system.

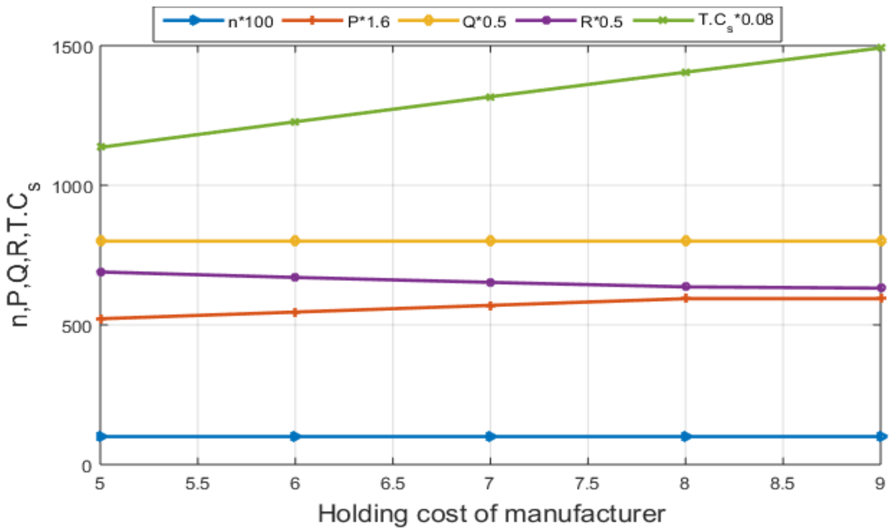

Figure 7. Manufacturer's holding cost effect

5.4. Effect of loading, unloading and transportation delay time

Figure 8 shows how the simulation model responds to changes in time spent in loading, unloading, and transporting the raw materials to the manufacturer warehouse. The figure shows that by increasing the delay time, the economic production quantity and numbers of full truckload shipments required increase. Moreover, both the numbers of truckload received and manufactured lot size due had a step function due to the truck load assumption as the vendor batch size. The manufacturer production rate and his re-order level also increase to minimize the shortage cost. The average total cost of the supply chain will, however, continue to increase because of the higher holding, production, and acquisition costs.

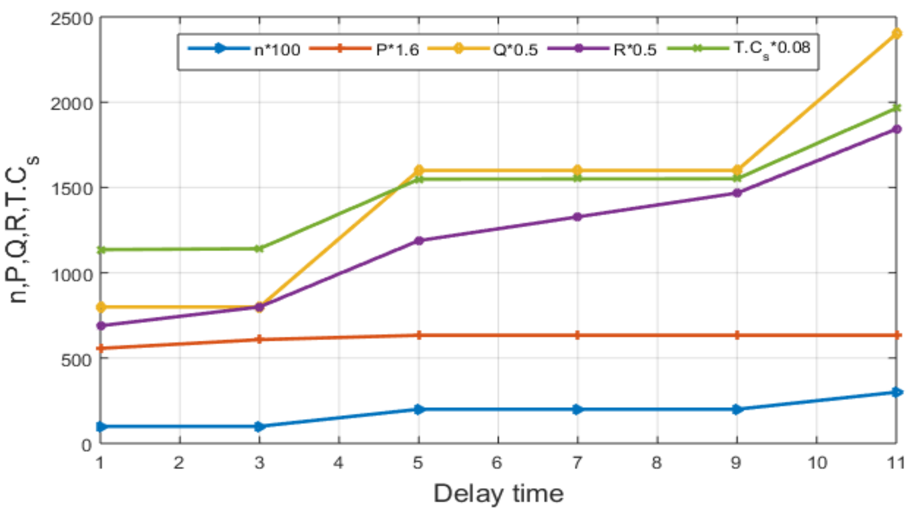

Figure 8. Effect of Loading, unloading and transportation delay time

6. The stochastic SVMM supply chain simulation problem

As reviewed in literature, the stochastic SVMM problem has numerous rooms for improvement and contributions. This section objective is to use simulation optimization to model SVMM integrated supply chain system with stochastic demand, while comparing two different distribution policies and finding optimal values for key decision variables using simulation optimization techniques. The policies proposed are:

- Joint reorder point (JRP)
- Vendor Managed Inventory (VMI).

A comprehensive description of both policies is presented below.

6.1. Single Vendor, Multiple Manufacturer Supply Chain

The Discrete event simulation model (DES) for the SVMM supply chain system is an expansion of the initially modeled SVSM problem in section 4. The SVMM simulation optimization model is modeled to imitate the problem described previously in section 3, and the same modelling methodology used for the SVSM simulation problem in Figure 1 was used. A warmup period of 3 years was determined using the Output analyzer software embedded in Arena 15.0, and this was trimmed off prior to collecting data from the simulation. The simulation run length is twenty (20) years, and each run is repeated ten (10) times. Furthermore, optimization is performed on the decision variables using Opt Quest optimization software. The decision variables for the JRP policy are the reorder point and the numbers of optimal shipments to be received by each manufacturer. For VMI policy, the numbers of optimal shipments to be received by each manufacturer, and the production stoppage time of the Vendor prior to starting another production cycle are the decision variables. These proposed policies relax the joint shipment, dependent ordering or equal numbers of order assumptions as found in most literatures.

6.2. Joint Reorder Point

This policy proposed a joint re-order point for the manufacturers within the supply chain. To operate this policy, the vendor must have sufficient information on the raw material level in each manufacturer’s inventory, possibly through data gathered from the Warehouse Management System (WMS). This guided the vendor on the best time to initiate raw material production in every cycle, and the optimal numbers of full-truck loads shipment to be delivered to each manufacturer, so that the average total cost is minimized. This policy is very suitable for supply chain systems with very high shortage cost.

To describe this policy, the vendor begins a new production cycle immediately the cumulative raw material in all manufacturers inventory/warehouses drop below the set re-order level called joint reorder point which is solely determines by the vendor who takes the lead. The simulation model for the JRP policy is a systematic extension of the previously validated SVSM simulation model and a detailed conceptual model chart is presented in Figure 9.

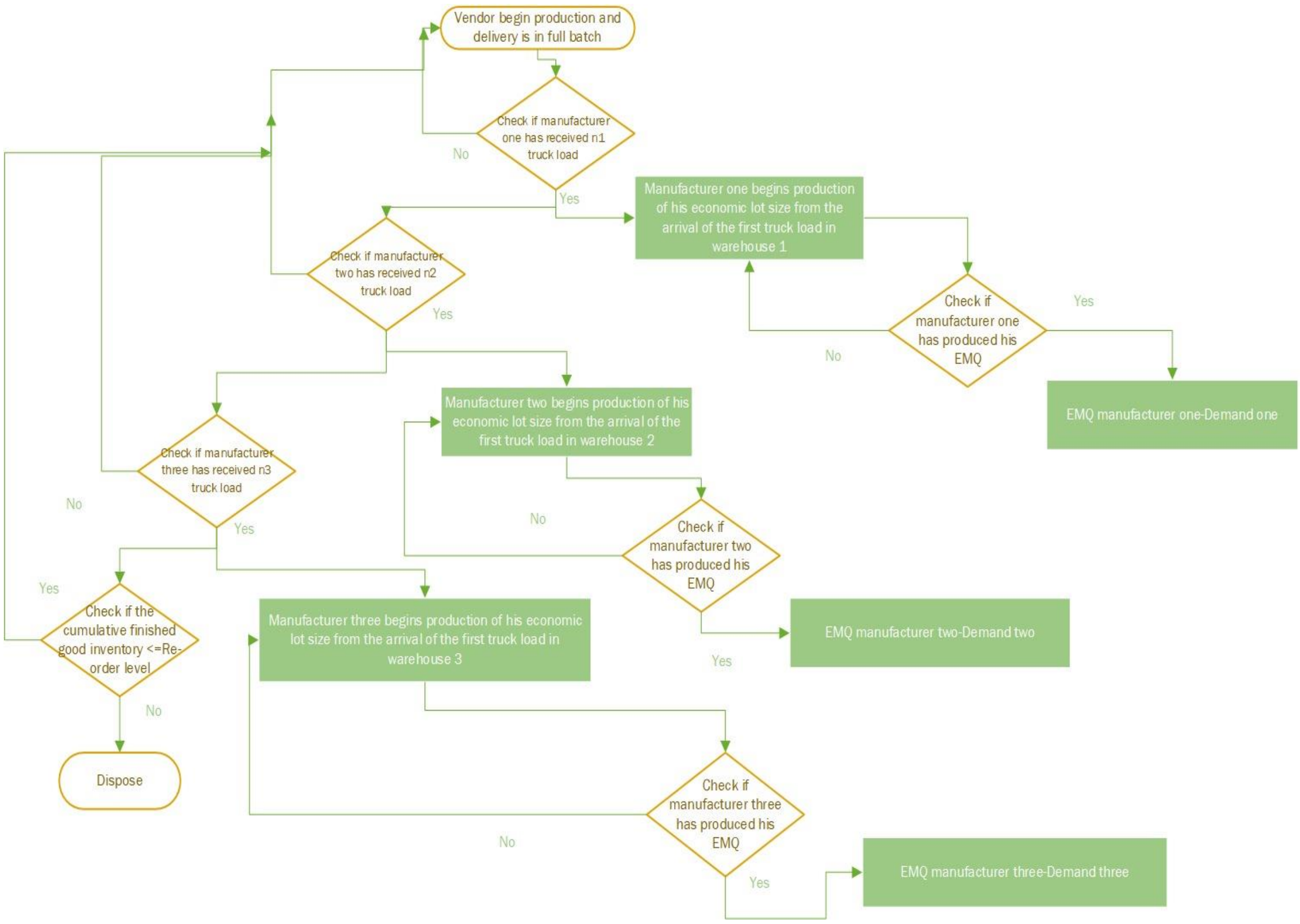

Figure. 9. Conceptual model for the JRP policy

6.2.1. Illustrative Example for Common Reorder Point Policy

To demonstrate the common re-order point policy using the proposed SVMM simulation model, values of parameters in Table 1 are used, with slight adjustment in manufacturers' expected demand rate, vendor's production rate and standard deviations as shown in Table 9.

Table 9. Additional parameters of the SVMM problem.

Manufacturer	Expected demand/unit time	Demand variability (σ)	Production rate/unit time
1	280	40	396
2	200	20	396
3	120	0.01	340
Vendor			3000

The decision variables are the joint reorder point, and numbers of full truck shipments sent to each manufacturer. The result of this policy as obtained from Opt Quest simulation optimization is shown in Table 10.

Table 10. Simulation optimization of the JRP and VMI policies

	JRP			VMI			VMI Financial savings or loss %
	Manufacturers			Manufacturers			
	1	2	3	1	2	3	
Number of shipments	12.00	8.00	5.0	11.00	8.00	5.00	-
Shortage cost of manufacturers	0	3965.20	0	4471.60	0	0	-12.77
Holding cost of manufacturers	486741.60	50090.60	127416.2	80326.6	118074.6	78741.94	58.27
Setup cost of + ordering cost + transportation cost	2247.20	1516.40	968.22	2100.7	1543	985.21	2.18
Production tool cost	9228.30	6154.70	3495.88	8611.2	6262.70	3557.21	2.37
Setup cost of vendor	1888.49			1862.4			1.38
Holding cost of vendor	1987.60			1937.2			2.53
Avg total cost	695700.40			308474.35			55.65

6.3. Vendor Managed Inventory Policy

The second policy proposed is the VMI policy. Here, the vendor decides both the numbers of shipment delivered to each manufacturer and the raw material production start time per cycle. If compared with CRP policy, the production of raw material by the vendor begins after a definite hold time in the vendor production cycle. This hold time is a decision variable and must be determine by the vendor who is assumed to take the lead in both scenarios. Like the CRP policy, the simulation model for VMI policy is equally an extension of the previously validated SVSM simulation model, and the detailed conceptual model describing the VMI is presented in Figure 10.

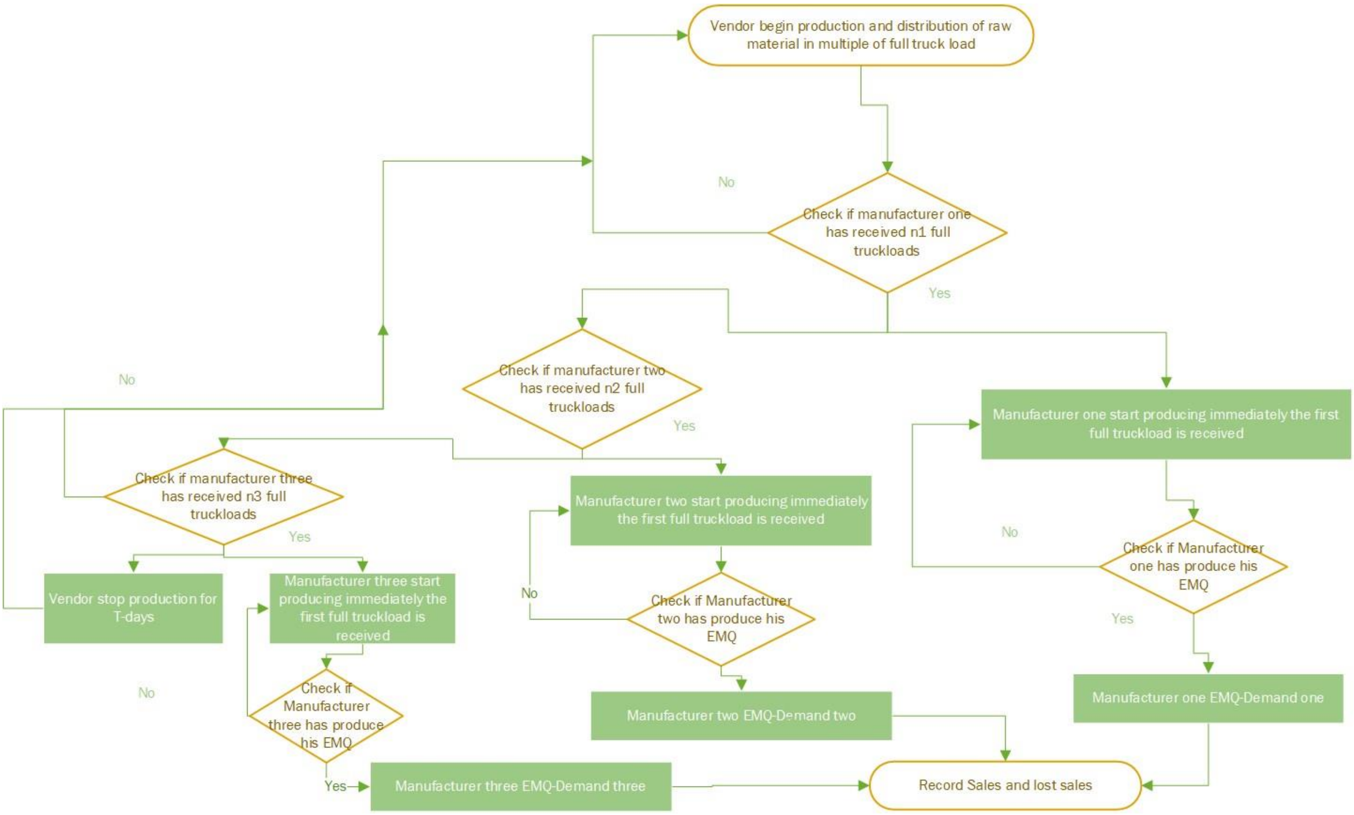

Figure 10. Conceptual model for the VMI policy

6.3.1. Illustrative Example for the VMI Policy

To test the VMI simulation model, the same parameters employed for the JRP policy was used. The decision variables are the number of truckload shipments sent by the vendor to each manufacturer, and the raw material production stoppage time after the last shipment is sent to the last manufacturer i.e this stoppage time is part of the vendor production cycle time. The result obtained from Opt Quest optimization is presented in Table 10.

Comparing the results obtained from both policies using the assumed parameters, it is observed that the VMI policy gives a financial savings of approximately 56% better than the JRP policy. This financial gap can be attributed to the high holding cost incurred by using the latter policy which forces the manufacturers to stock more raw materials i.e., production and supply of this material can easily be triggered by the independent demand of any of the manufacturers, once the cumulative raw material in all warehouses fall below the set reorder point without any attention to the difference in level inventory in each manufacturer warehouse. Hence, adding more uncertainty to the supply chain system. This contrasts with the VMI policy where the vendor manages the manufacturer replenishment cycle by determining the most suitable time to produce and ship the raw material base on the holistic assessment of the entire supply chain system rather than warehouse inventory alone. Hence, with the VMI policy, supply chain system behaves more harmoniously as a single system.

6. Conclusion

This paper set out to develop a SVMM simulation optimization model, a subject that had gain little attention from scholars, who had placed stringent conditions/assumptions to develop a mathematical formulation for the problem. This paper provides an insight on simulation modelling as an alternative approach for solving this type of problem. This was done by comparing results obtained from both Simulation and Mathematical modelling of the SVSM version of the problem (AlDurgam et al., 2017), at a very low standard deviation (σ) to eliminate the randomness in demand, thus making the problem deterministic (Ignall et al., 1978).

We equally investigate the robustness of the famous Continuous review (Q, R) policy which is widely adopted in mathematical modelling or formulation of multi-echelon supply chain system involving random/stochastic demand. The results obtained from both models at different demand standard deviation were compared, and coefficient of variation was suggested as a judgement criterion of when it is more suitable to adopt simulation.

Lastly, through the validated SVSM simulation model, we relax several assumptions like the single manufacturer, joint shipment, dependent ordering where manufacturers are tied to strict conditions like equal numbers of shipments, and many replenishment conditions that ensure that all manufacturers re-order criteria are met before replenishment. This is achieved through two distribution policies (VMI and JRP) and both were demonstrated using the same input parameter as representative example. Opt Quest optimization software in Arena 15.0 was used to determine for the vendor the best stationary distribution approach for both policies. VMI policy gives better financial savings base on its long run average cost that was reduced, due to much lower inventory holding cost as compared to the JRP policy. The JRP policy ensures that all manufacturers produce more goods to avoid lost sales as raw material replenishment point can easily be influenced by the independent demand of the manufacturers.

References

Abdul-Jalbar, B., Gutiérrez, J.M., & Sicilia, J. (2008). Policies for a single-vendor multi-buyer system with finite production rate. Decision Support Systems, 46(1), 84-100.

AlDurgam, M., Adegbola, K., & Glock, C.H. (2017). Single-vendor single-manufacturer inventory model with stochastic demand and variable production rate. International Journal of Production Economics, 59(1), 297-304.

Aritonang, K., Nainggolan, M., & Djunaidi, A. V. (2020). Integrated Supply Chain for a Single Vendor and Multiple Buyers and Products with Crashing Lead Time. *International Journal of Technology*, *11*(3), 642-651.

Banerjee, A. & Burton, J.S. (1994). Coordinated vs. independent inventory replenishment policies for a vendor and multiple buyers. International Journal of Production Economics, 35(1), 215-222.

Ben-Daya, M., As'ad, R., & Nabi, K.A. (2019). A single-vendor multi-buyer production remanufacturing inventory system under a centralized consignment arrangement. Computers & Industrial Engineering, 135, 10-27.

Ben-Daya, M., Hassini, E., Hariga, M., & AlDurgam, M. M. (2013). Consignment and vendor managed inventory in single-vendor multiple buyers supply chains. International Journal of Production Research, 51(5), 1347-1365.

Bylka, S. (1999). A dynamic model for the single-vendor, multi-buyer problem. International Journal of Production Economics, 59(1), 297-304.

Castellano, D., Gallo, M., & Santillo, L.C. (2020). A periodic review policy for a coordinated single vendor-multiple buyers supply chain with controllable lead time and distribution-free approach. 4OR, 19(3), 347-388.

Chan, C.K., & Kingsman, B.G. (2007). Coordination in a single-vendor multi-buyer supply chain by synchronizing delivery and production cycles. Transportation Research Part E: Logistics and Transportation Review, 43(2), 90-111.

Chan, C.K., & Lee, Y.C.E. (2012). A co-ordination model combining incentive scheme and co-ordination policy for a single-vendor–multi-buyer supply chain. International Journal of Production Economics, 135(1), 136-143.

Chan, C.K., Fang, F., & Langevin, A. (2018). Single-vendor multi-buyer supply chain coordination with stochastic demand. International Journal of Production Economics, 206, 110-133.

Chan, C.K., Lee, Y.C.E., & Goyal, S.K. (2010). A delayed payment method in co-ordinating a single-vendor multi-buyer supply chain. International Journal of Production Economics, 127(1), 95-102.

Chu, C.L., & Leon, V.J. (2008). Single-vendor multi-buyer inventory coordination under private information. European Journal of Operational Research, 191(2), 485-503.

Darwish, M.A., & Odah, O.M. (2010). Vendor managed inventory model for single-vendor multi-retailer supply chains. European Journal of Operational Research, 204(3), 473-484.

Fauza, G., Amer, Y., Lee, S.H., & Prasetyo, H. (2016). An integrated single-vendor multi-buyer production-inventory policy for food products incorporating quality degradation. International Journal of Production Economics, 182, 409-417.

Glock, C.H., & Kim, T. (2014). Container management in a single-vendor-multiple-buyer supply chain. Logistics Research, 7, 1-16.

Hoque, M.A. (2008). Synchronization in the single-manufacturer multi-buyer integrated inventory supply chain. European Journal of Operational Research, 188(3), 811-825.

Hoque, M.A. (2011). An optimal solution technique to the single-vendor multi-buyer integrated inventory supply chain by incorporating some realistic factors. European Journal of Operational Research, 215(1), 80-88.

Ignall, E.I., Kolesar, P., & Walker, W.E. (1978). Using simulation to develop and validate analytic models: some case studies. Journal of Operation Research, 26(2), 237-253.

Jha, J.K., & Shanker, K. (2013). Single-vendor multi-buyer integrated production-inventory model with controllable lead time and service level constraints. Applied Mathematical Modelling, 37(4), 1753-1767.

Kim, C.O., Jun, J., Baek, J.K., Smith, R.L., & Kim, Y.D. (2005). Adaptive inventory control models for supply chain management. The International Journal of Advanced Manufacturing Technology, 26(9-10), 1184-1192.

Rad, R.H., Razmi, J., Sangari, M.S., & Ebrahimi, Z.F. (2014). Optimizing an integrated vendor-managed inventory system for a single-vendor two-buyer supply chain with determining weighting factor for vendor 's ordering cost. International Journal of Production Economics, 153, 295-308.

Sarkar, B., Majumder, A., Sarkar, M., Kim, N., & Ullah, M. (2018). Effects of variable production rate on quality of products in a single-vendor multi-buyer supply chain management. The International Journal of Advanced Manufacturing Technology, 99(1), 567-581.

Taleizadeh, A.A., Niaki, S.T.A., & Makui, A. (2012). Multiproduct multiple-buyer single-vendor supply chain problem with stochastic demand, variable lead-time, and multi-chance constraint. Expert Systems with Applications, 39(5), 5338-5348.

Tarhini, H., Karam, M., & Jaber, M.Y. (2020). An integrated single-vendor multi-buyer production inventory model with transhipments between buyers. International Journal of Production Economics, 225, 107568.

Vandana, & Sana, S.S. (2020). A two-echelon inventory model for ameliorating/deteriorating items with single vendor and multi-buyers. Proceedings of the National Academy of Sciences, India Section A: Physical Sciences, 90(4), 601-614.

Wensing, T. (2011). Periodic review inventory systems. Lecture notes in Economics and Mathematical Systems. London New York: Springer Heidelberg Dordrecht.

Woo, Y.Y., Hsu, S.L., & Wu, S. (2001). An integrated inventory model for a single vendor and multiple buyers with ordering cost reduction. International Journal of Production Economics, 73(3), 203-215.

Yang,P.C., & Wee, H.M. (2002). A single-vendor and multiple-buyers production- inventory policy for a deteriorating item. European Journal of Operational Research, 143(3), 570-581.

Zavanella, L., & Zanoni, S. (2009). A one-vendor multi-buyer integrated production-inventory model: The 'Consignment Stock' case. International Journal of Production Economics, 118(1), 225-232.