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Modelling and Analysis of Hospital Inventory Policies during COVID-19 Pandemic

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Abstract: The global coronavirus pandemic (COVID-19) started in 2020 and is still ongoing today. Among the numerous insights the community has learned from the COVID-19 pandemic is the value of robust healthcare inventory management. The main cause of many casualties around the world is the lack of medical resources for those who need them. To inhibit the spread of COVID-19, it is therefore imperative to simulate the demand for desirable medical goods at the proper time. The estimation of the incidence of infections using the right epidemiological criteria has a significant impact on the number of medical supplies required. Modeling susceptibility, exposure, infection, hospitalization, isolation, and recovery in relation to the COVID-19 pandemic is indeed crucial for the management of healthcare inventories. The goal of this research is to examine the various inventory policies such as reorder point, periodic order, and just-in-time in order to minimize the inventory management cost for medical commodities. To accomplish this, a SEIHIsRS model has been employed to comprehend the dynamics of COVID-19 and determine the hospitalized percentage of infected people. Based on this information, various situations are developed, considering the lockdown, social awareness, etc., and an appropriate inventory policy is recommended to reduce inventory management costs. It is observed that the just-in-time inventory policy is found to be the most cost-effective when there is no lockdown or only a partial lockdown. When there is a complete lockdown, the periodic order policy is the best inventory policy. The periodic order and reorder policies are cost-effective strategies to apply when social awareness is high. It has also been noticed that periodic order and reorder policies are the best inventory strategies for uncertain vaccination efficacy. This effort will assist in developing the best healthcare inventory management strategies to ensure that the right healthcare requirements are available at a minimal cost.

Keywords: COVID-19; SEIR model; pandemic; mathematical modeling; inventory; healthcare supplies

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1. Introduction

The advent of the Coronavirus in 2019, which is also referred to as COVID-19, has drastically affected peoples' lives as well as the healthcare system of the countries. It is highly contagious, hence making it very lethal. The World Health Organization (WHO) coronavirus dashboard has documented more than 754 million positive cases worldwide as of today, (5 February 2023) [1]. Nearly all industries have been impacted by COVID-19's social, economic, and political changes and turmoil, but the healthcare industry has been hit the worst because it has been at the vanguard of the fight against the virus. As the number of patients at the hospital rises daily, pressure mounts and there is an alarming rise in the need for healthcare supplies namely personal protective equipment (PPE) kits, medications, and ventilators, among other things [2]. This virus spreads quickly, which increases the number of infected people and mortality rates. Finding a cure or treatment for COVID-19, however, is time- and money-consuming because it is a novel virus with unknown characteristics and is also changing its nature continuously. PPE is one method for preventing the spread of COVID-19 among medical personnel and the general public [3]. However, on the other hand, due to lockdowns and other restrictions employed by the governments to curb the COVID-19 spread, the whole supply chain and movements of goods have been disturbed drastically. As a result, the majority of countries are experiencing significant shortages of medical supplies just when they are needed the most [4,5].

Manufacturing facilities, transportation infrastructure, and distribution networks make up supply chains [6]. These supply chain networks have previously experienced disruptions, but they only included a single country, a single facility closure, or a loss of a single raw material source [7]. Due to limitations on cross-border travel and shipping, as well as the widespread cancellation of international flights, the pandemic has crippled transportation networks. The international supply chain's distribution networks have been further weakened by 68 countries restricting the export of personal protective equipment supplies to other nations [4]. Most healthcare systems, and even entire nations, now maintain a modest inventory of medical goods in anticipation of future demand due to supply chain optimization [8].

Over the past decade, governments, practitioners, and academics have begun to pay more attention to the management of the healthcare supply chain (HCSC), but COVID-19 has given it a significant boost [9–11]. The unusual risk and uncertainty surrounding the availability, accessibility, and price of medical goods caused panic buying and stockpiling as the COVID-19 pandemic's effects grew, leading to unforeseen demand shocks, stock-outs, and a pattern of HCSC interruptions [12]. Since the majority of research on managing medical stocks was conducted outside of a pandemic context, it is important to emphasize inventory management strategies that maximize profit, minimize cost, and generally optimize HCSCs through stochastic and periodic reviews, approximate inventory control using simulation, or any other techniques [13–15]. However, in a pandemic situation where governments, healthcare providers, and humanitarian organizations are all battling clogged inventory operations, improved lean inventory systems seem paradoxical. Costs, revenues, and other performance optimization goals are superseded by the requirement to guarantee universal access to the best medical supplies during pandemics. Governments, businesses, and humanitarian logistics organizations cannot operate in a network with overstretched inventories [12].

According to behavioral economics methods for making decisions in the face of uncertainty, COVID-19 is special compared to other natural disasters [16,17]. Due to the lack of knowledge about the pandemic and the unpredictability of changes in consumer behavior, general optimization strategies are therefore likely to fail. Hence, pandemic-based inventory management and optimization are required. Therefore, to reduce the cost of inventory management for medical commodities, this research aims to analyze various inventory policies including reorder point, periodic order, and just-in-time. To do this, a SEIHIsRS model has been used to appreciate COVID-19 dynamics and ascertain the proportion of infected persons hospitalized. Based on this data, numerous scenarios are created, taking into account the lockout, social awareness, etc., and a suitable inventory policy is advised to lower the cost of inventory management.

In the next section the related research literature is presented. Section 3 explains the developed simulation model. Section 4 presents the outcomes obtained and a discussion is made based on the results. Finally, Section 5 summarized the conclusions inferred from the research work.

2. Literature Survey

The COVID-19 pandemic has caused an extreme shortage of critical healthcare equipment and resources such as PPE kits, ICU beds, Ventilators, test kits, physicians, etc. Travel restrictions that were applied to control the spread of COVID-19 have led to disruptions in all the supply chains. The production rates also decreased due to the isolation of workers who got infected. Dube et al. [18] studied the supply chain resilience in the case of ventilator procurement during COVID-19 through an equifinality approach. The study investigated how three European governments successfully secured the supply of ventilators amid high global demand and supply disruptions during the first wave of COVID-19. The study gave an insight into how and why the buying organizations with varying initial conditions successfully bridged demand and supply disruptions.

The case-based research approach was adopted using supply resilience capabilities such as flexibility, redundancy, agility, collaboration, and visibility across three cases. Case countries were selected with varying initial conditions such as available ventilator capacity at the onset of the pandemic and available sourcing strategies, i.e., local versus global and single versus multiple sourcing. The selected case countries were UK, Germany, and Switzerland. The central government or government agency of these countries with procurement remit were the buying organizations. Data were collected from 124 online documents and multiple secondary sources. The data was then analyzed qualitatively and coded for information on initial conditions and response strategies by each of the three countries. Both within- and cross-case analyses were performed. The within-case analysis was helpful for the deep understanding of unique characteristics, initial conditions, and response strategies in each country. A cross-case analysis was useful to identify critical patterns across the three countries in terms of response strategies and supply resilience. Results showed different paths to supply resilience of three government contingents and presented accompanying prepositions. Dar et al. [19] provided a framework to approach mechanical ventilation device shortage during COVID-19. They presented strategies to reduce demand, maximize availability, as well as create new supply sources and staffing needs.

Sigala 2021 [20] analyzed different types of disruptions in the PPE supply chain during COVID-19 and proposed mitigating strategies. A conceptual framework was developed for the cause of disruptions during health emergencies based on the literature. It was then utilized to collect qualitative data from the interviews with PPE supply chain experts in COVID-19. A system dynamics model was developed based on the literature and empirical data from interviews. The mechanism causing PPE supply chain disruptions was identified and mitigating strategies were suggested. Bhaskar et al. [21] analyzed the failure of the global supply chain during the COVID-19 pandemic which resulted in an extreme shortage of critical medical supplies. The study identified key problems associated with the current global supply chain and suggested the lean supply chain is inappropriate for the healthcare supply during the COVID-19 crisis. A supply chain integration framework was built around strong governance, less bureaucracy, and the use of technology. The proposed model identifies critical stockpiles and increases production efficiency through technologies such as data analytics and blockchain. The elements of the proposed model were (1) a national supply chain command center, (2) a national procurement center, (3) a national supply chain quality control center, (4) a national distribution center, (5) blockchain as connector, and (6) predictive big data analytics for supply chain demand forecasting.

Arora et al. [22] presented the importance of supply chain management in healthcare. The study analyzed the shortcoming in healthcare and recommended control measures for improvement in healthcare. The study addresses techniques used in healthcare for effective supply chain management. The supply chain cycle was divided into stakeholders in healthcare, and subsystems of healthcare such as healthcare information systems, pharmacy supply chain, blood bank supply chain, and patient safety supply chain. An integrated supply chain was suggested that links the hospital department, operations, and revenue cycle. The integrated supply chain ensures the availability of medicine or product at the right time, minimizes wastage, as well as maximizes patient care, and coordination between different departments for reduced human error. The study suggested the use of integrating subsystems, streamlining of workflow, as well as utilization of RFID (radio-frequency identification) technologies, standard product code, and Global Identification Number (GIN) for the integration.

Raj et al. [23] investigated the supply chain issues and supply chain challenges faced by manufacturing organizations during COVID-19 in India (an emerging economy). They presented a framework under dynamic capability theory and supply chain resilience to analyze challenges and propose mitigating strategies. Ten main challenges were identified based on the literature, consultations with experts, and evaluation of new articles. Grey Decision-making Trial and Evaluation Laboratory was applied to analyze the relationship between different supply chain challenges. The scarcity of labor and materials was found to be a significant challenge. The inconsistency of supply was found to correlate with most other factors. Okeagu et al. [24] discussed supply chain management strategy in a time of crisis such as COVID-19. In addition, the paper addresses governance and financing, emergency protocols, emergency procurement and supply chain, supply chain gaps, and ways to address them.

Cohen et al. [25] investigated four major factors and their interactions that contributed to the severe deficiency of PPE in the US during COVID-19. It was shown that extreme shortages of PPE arose due to the compounding effects of the mentioned factors.

1. The budgeting model in hospitals incentivizes minimizing cost instead maintaining a sufficient supply of PPE.
2. Depletion of PPE inventories due to the extremely high demand by healthcare and panicked marketplace.
3. Failure of the federal government to continue and disburse domestic inventories.
4. The disruptions in the global supply chain of PPE induced the dearth of PPE exports to the US.

Chen et al. [26] investigated the supply chain of critical medical devices and the difficulties in increasing their production during COVID-19. To improve the supply chain response to a healthcare emergency, it was suggested that government play a crucial role in coordinating various companies and customers with a combination of policies and incentives for the increased inventory and reserve capacity. It was also suggested to develop processes and procedures for the flexible and efficient movement of resources. Park et al. [27] studied the global shortage of PPE amid the COVID-19 crisis. They presented an overview of the PPE market, their supply chains, significant supply chain bottlenecks, and ways to tackle them. The knowledge regarding the presence of products in the market, production capacity, and supply chain response was found to be critical for PPE during the pandemic. Jiang et al. [28] studied the robust supply chain and the decision-making of multinational corporations during uncertainties. The robust supply chain is designed for the worst-case scenario where the allotment of resource does not relate to the standard economic theories but pursue a heuristic rule known as probability matching. A multinational optimizing strategy leads to the allocation of resources that is suboptimal from the individual position, but it discards the possibility of any supply disruptions.

Snowdon and Saunders [29] discussed the significance of the healthcare supply chain and presented a case study on healthcare supply chain management during COVID-19 in Nova Scotia. The main aim of the study was to comprehend the relationship between the central leadership policies, crucial supply chain management actions and capacity, and healthcare responsiveness in Canadian provinces. The Nova Scotia case study revealed the significance of the dedicated supply chain that combines all provincial healthcare enterprises. Spieske et al. [30] performed a multi-tier case study involving six manufacturers of medical supplies and three hospital factions specifically dealing with COVID-19 to study supply chain resilience using resource-dependent theory. The study found bridging measures to be more effective than buffering measures. In addition, upstream procurement and sharing of resources between the hospitals were found to have superior risk mitigation. Lua et al. [31] evaluated the healthcare supply chain management in Hong Kong and the USA in the COVID-19 milieu. The study focused on the critical elements during the pandemic such as respirators, critical medical supplies, blood supply chain, disinfectants, and human remains and logistics. They identified key challenges and proposed strategies to enhance the efficaciousness of the healthcare supply chain.

3. Model Description

The systems dynamic (SD) methodology [32], a simulation procedure for understanding the nonlinear nature of convoluted systems that is often employed for feedback loop evaluation, is used in this study. Stocks (indicated using a box), flows (denoted through valves with arrows), auxiliary, and delay components are the primary elements of this modeling approach.

In order to examine how the supply of healthcare affects the spread of COVID-19, a modified version of the prominent compartmental disease diffusion model called the Susceptible-Exposed-Infected-Recovered (SEIR) model was employed [33,34]. The authors have discussed this upgraded model known as Susceptible-Exposed-Infected-Hospitalized-Isolated-Recovered-Susceptible (SEIHIsRS) in great length in a recent article [35]. The goal of utilizing this model is to anticipate the number of hospitalized patients in the Kingdom of Saudi Arabia (KSA) at a specific moment and, as a result, build an inventory model that accurately predicts the appropriate inventory policy. Five categories represent the entire population: Susceptible (S), Exposed (E), Infected (I), Hospitalized (H), and Isolated (I_s)–Recovered (R) in a high-level stock-flow diagram as shown in Figure 1. The previously published article from the same research project contains a comprehensive explanation of this model [35]. The details here would unnecessarily extend the manuscript's length. However, the important notations utilized in the model (see Figure 1) are presented in Table 1 to get an understanding of the inventory model.

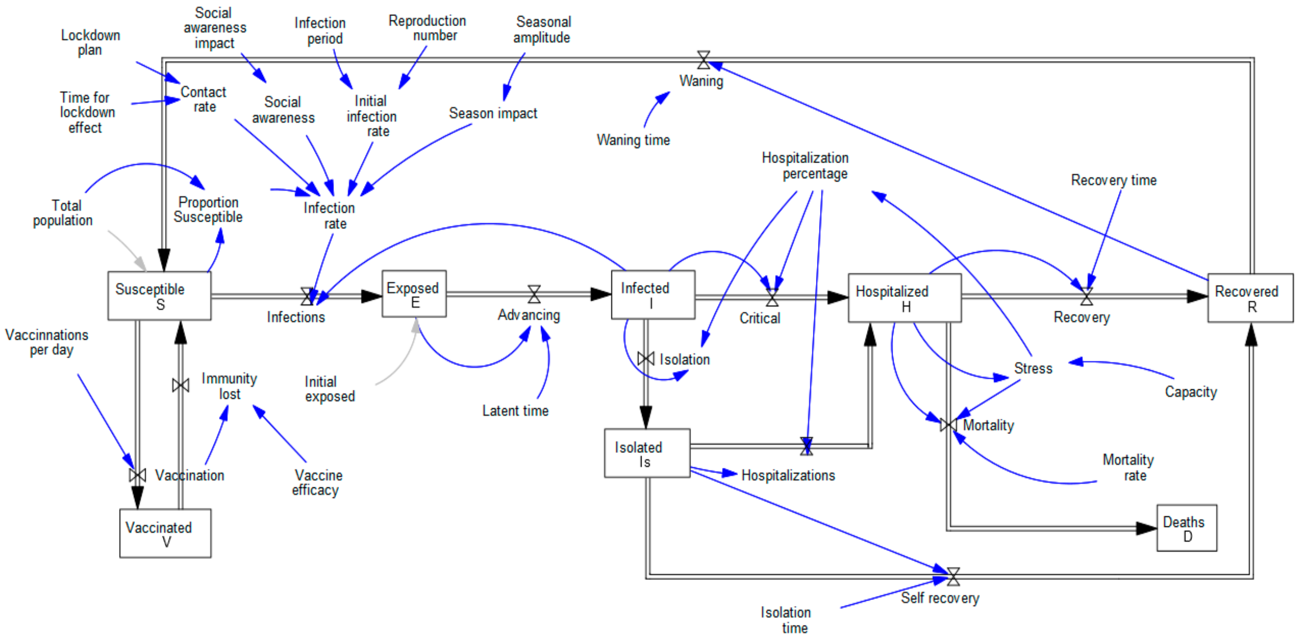


Figure 1. SEIHI$_s$RS pandemic model for COVID-19 [35].

Table 1. Symbols used in the SEIHI$_s$RS model.

Notations	Description
Susceptible (S)	Persons who are at risk of the virus
Exposed (E)	People who are exposed to the virus
Infected	Persons who are diseased and contagious
Hospitalized (H)	Patients receiving medical attention in the hospital
Isolated	Individuals lodged in confinement
Recovered	People rehabilitated from the infection
Deaths	Patients died of COVID-19
Vaccinated	Inoculated population
Capacity (C)	Maximum patients that can be treated by the hospital

Table 1. *Cont.*

Notations	Description
Initial Infection Rate	The infection rate without any extra affecting factor
Infection Rate	The probability of infection which depends on many contributing elements
Hospitalization Percentage	Admittance percentage of the COVID-19 patients
Mortality rate	The proportion of COVID-19 patients dying every day
Infection Period	The extent of a person's contagiousness
Latent time	The period after which an exposed individual becomes symptomatic
Time for lockdown effect impact	Time after which lockdown implications are apparent
Isolation time	The extent of patient's confinement before self-recovery happens
Recovery time	Length of stay in the hospital after which the patient recuperates through medication
Waning time	Time after which recovered individuals lose their immunity
Vaccination per day	Delivered vaccination dosages each day
Contact rate	The frequency at which people come in contact with each other and transmit the disease
Proportion susceptibility	Percentage of the initial population resided in the less populated area
Seasonal amplitude	The intensity with which the season affects the transmission
Social awareness impact	Ability to social awareness impact the curb of disease transmission
Reproduction number	Frequency of virus's reproduction
Lockdown plan	Setting up the lockdown plan
Stress	Pressure due to overloading
Vaccine efficacy	Immunization performance

The fine-tuned SEIHIsRS developed in [35] provided the average hospitalization within KSA. This information was then used to develop the inventory model shown in Figure 2. The following is a description of this model. The daily consumption of inventory items, which varies depending on the number of units needed for each patient, is provided by the hospitalized population from SEIHIsRS. For instance, four PPE kits are needed each day per patient because a doctor requires one kit when he or she sees the patient once a day, a nurse needs two kits when she visits the patient twice a day, and a cleaning aid uses one kit when he or she enters the patient's room once a day. Daily consumption estimation is crucial for an efficient inventory model because it controls the units consumed, forecasted demand, or the periodic order. The forecasted demand is nothing but the demand for the next day. A variety of strategies, as depicted in the model, can be utilized to place the order depending on the requirements. Reorder point policy (ROP), Periodic order policy (POP), and Just-in-Time (JIT) are the three inventory policies that have been examined in the investigation. These different order placement procedures or policies should be selected depending on the model's minimal cumulative cost. In the POP, there is an inventory replenishment period after which the order is placed routinely. Similarly, the ROP is based on the minimum inventory requirement and mandates that an order be placed as soon as the minimum inventory level is reached. In JIT, the order is placed only when the requirement arises. Consequently, depending on the order, the order is placed which in turn governs the order's rate and the order backlog. In addition to other factors, the order policy takes the order backlog into account and allocates the order accordingly. After a predetermined lead time, the hospital receives the ordered inventory after the order is placed. The lead time is the interval between placing an order and the hospital receiving it. As a result, lead time and order rate affect the rate at which the items are supplied. The total cost per day is determined to determine the overall cost of a placed order or the effectiveness of a specific inventory policy. The order cost, processing cost, holding cost, and cost of products are considered when calculating the overall cost per day. The equations used to define the different variables and the governing equations of this model for individual compartments can be illustrated utilizing Equations (1)–(15). The constants deployed in the model, their values, and their units are reported in Table 2.

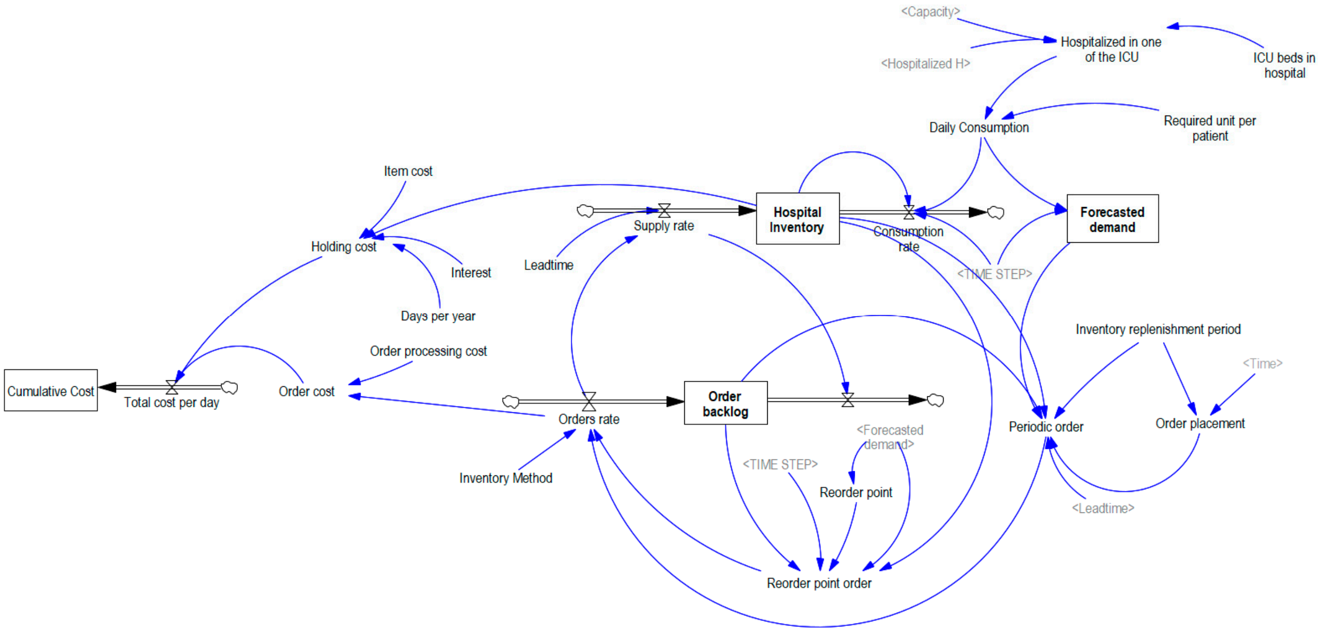


Figure 2. Proposed model to estimate the hospital inventory.

Table 2. Constants used in the inventory model.

Constant	Value	Units
Days per year (D_Y)	365	Day
ICU beds in hospital (ICU_B)	200	Person
Interest (I_i)	0.25	1/Year
I_{RP}	1 or 7	Day
Item cost (I_C)	35	SAR/Unit
L_T	random normal (5, 1) Otherwise 1 day for JIT	Day
OP_C	75	SAR
Required unit per patient (R_U)	4	Unit/(Person * Day)
TIME STEP (T_s)	1	Day

A simulation software named Vensim has been used to replicate the inventory procedure mentioned above. The Vensim® (Version 9.3.4, Ventana Systems, Inc., Harvard, MA, USA) is a commercial software that is used to build the SD model, and it is based on the Euler integration approach with a time-step of 1. The benefit of this application is that it enables continuous simulation for SD by delivering a graphical modeling interface for stock-and-flow and causal loop diagrams where text-based equations are incorporated. Figure 2 depicts a graphical illustration of the model built in Vensim to simulate the inventory process. The leading intent of developing this model is to track and manage the effects of the disease as well as to choose the optimum inventory strategy for various COVID-19 management scenarios in KSA. The various scenarios include various lockdown strategies, the effect of social awareness, and the impact of various vaccination types. The different scenarios are as follows.

3.1. Inventory Management under Different Lockdown Plans

A lockdown is a mode of seclusion in which people, a group of people, or a whole country are required to stay where they are. It limits movement or activity in a society while allowing only routinely operating businesses that offer necessities like commodities and services. A lockdown may require varying degrees of enforcement depending on the situation [36]. The economy may be severely harmed by a prolonged lockdown. Long-term psychological effects could also include boredom, unhappiness, and anxiety about falling ill or running out of resources, etc. The shutdown can significantly affect hospital inventory management.

There are three types of lockdown plans: full lockdown (FLD), partial lockdown (PLD), and without lockdown (WLD). As a result, it is discovered that in order to reduce the inventory cost of the pandemic, a specific inventory policy for a certain lockdown plan must be implemented.

3.2. Inventory Management under Social Awareness Impact

Social awareness and individual behavior can prevent the spread of infectious diseases. These campaigns can be carried out in many ways, from government directives to public pressure [37]. In the case of COVID-19, outcomes of public awareness efforts and individual initiatives comprise of better hygiene practices (sanitization), the wearing of masks and other personal protective equipment, social withdrawal, etc. These initiatives show a population's willingness to participate in infection control, which can lessen the burden placed on hospitals and barriers to the implementation of preventive policies, both of which have an effect on the management of various goods in inventory. Therefore, in this situation, the best inventory policy is examined based on the level of social awareness (low, high, and extremely high).

3.3. Inventory Management under a Different Type of Vaccination

All through the COVID-19 period, several vaccinations have been introduced; however, their efficacies alter substantially. For example, Pfizer has a 95% efficacy rate, compared to 76% for Astra Zeneca [38]. This intimates that the brand of the vaccine may also have a compelling role in constraining the transposal of COVID-19. Thus, the consequence of variable vaccine efficacies on infections, hospitalizations, and fatalities can increase the load on service entities such as the hospital. This section enables us to comprehend how the government policy on the effectiveness of immunizations should be taken into consideration while doing inventory management at the hospital level.

The model built and equations used in the Vensim platform to determine the hospital's ideal inventory policy in the COVID-19 scenarios are described as follows. The first step is to ascertain hospital's the consumption rate (C_R), or the rate at which the inventory items are being consumed. This information is required for understanding the benefits of the various inventory policies employed in the model. The C_R (measured in units/day), which can be computed using Equation (1) depends on the hospital inventory, number of patients in the ICU, required units per patient, daily consumption, and total cost. If the hospital inventory is more than daily consumption, it means that C_R is equal to daily consumption; otherwise, it is equal to hospital inventory. Before proceeding, it is important to establish here that the equations in the manuscript are defined in the Vensim syntax. Past studies have also employed this syntax because it is difficult to standardize the Vensim equations. Furthermore, the equations represented in the Vensim syntax help the readers comprehend the model well and replicate it easily at their end.

$$C_R = \text{IF THEN ELSE}\left(\frac{H_I}{T_S} > D_C, D_C, \frac{H_I}{T_S}\right) \quad (1)$$

where H_I represents the hospital inventory and is measured in units.

D_C stands for the daily consumption, i.e., the items consumed per day (specified in units/day).

T_s is the time step in days (see Table 2).

The daily consumption, D_c, that depends on the hospitalized patients and the number of units required per patient can be defined using Equation (2).

$$D_C = R_U \times H_{ICU} \quad (2)$$

where R_U indicates units required per patient (refer to Table 2).

H_{ICU} symbolizes the count of patients hospitalized in one of the ICUs and is expressed in person.

The number of patients hospitalized in the *ICU* is computed using Equation (3) and it depends on the number of patients treated with infectious disease in the hospital (H), the count of persons adequately treated by the hospital (C), and the number of *ICU* beds in the hospitals (ICU_B).

$$H_{ICU} = \frac{H}{\left(\frac{C}{ICU_B}\right)} \quad (3)$$

In addition, the hospital inventory which is a function of supply rate, consumption rate, and lead time, can be estimated using Equation (4) in the Vensim model.

$$H_I = \text{INTEG}\ ((S_R - C_R),\ \text{Initial value} = \text{orders} \times (L_T)) \quad (4)$$

where S_R represents the rate at which the items are being supplied and is measured in units/day. It can be using Equation (5).

L_T stands for the time between the order placed and the order received, and it is expressed in day (refer to Table 2).

$$S_R = \text{DELAY MATERIAL}\ (O_R, L_T, 0, 0) \quad (5)$$

Another essential aspect of the inventory model is the forecasted demand (F_D), which is expressed in units per day and is the demand for the following day. Equation (6) is used to estimate it.

$$F_D = \text{INTEG}\ \left(\left(\frac{D_C - F_D}{T_S}\right), D_C\right) \quad (6)$$

Moreover, there is a cost associated with maintaining inventory, which is crucial to integrate into the inventory model. It is known as the holding cost (H_C) and can be defined using Equation (7). The holding cost is expressed in SAR/day and covers expenses for rent, furnishings, electricity, staff, etc.

$$H_C = \frac{H_I \times I_C \times I_i}{D_Y} \quad (7)$$

where I_C is the item cost (see Table 2).

I_i stands for Interest (refer to Table 2).

D_Y represents the number of days in a year (refer Table 2).

Order backlogs (O_B), which are quantified by Equation (8), are always a possibility in inventory management. It is defined as the number of units which was ordered but are not shipped yet.

$$O_B = \text{INTEG}\ ((O_R - S_R),\ 0) \quad (8)$$

The rate at which the order is placed, O_R (in units/day) is computed using Equation (9).

$$O_R = \text{IF THEN ELSE (Inventory Method} = 1, POP, ROP) \quad (9)$$

where *POP* is the periodic order policy.

ROP is the reorder point policy.

POP, where the order is placed periodically and *ROP* which depends on the minimum inventory can be estimated using Equations (10) and (11) respectively.

$$POP = \text{IF THEN ELSE (Order placement} <> 0, \text{IF THEN ELSE } (F_D \times (L_T + I_{RP}) > (H_I + O_B), (F_D \times (L_T + I_{RP}) - H_I - O_B)/\text{Order placement}, 0), 0) \quad (10)$$

$$ROP = \text{IF THEN ELSE } ((H_I + O_B)/T_S < R_P, (L_T \times F_D), 0) \quad (11)$$

where I_{RP} expressed in day is the time after which the order is automatically placed.

The reorder point (R_P) at which action is taken to replenish the item inventory stock, is obtained using Equation (12), while order placement is expressed using Equation (13).

$$R_P = F_D \times L_T + z \times F_D \quad (12)$$

where z is the number of standard deviations at the service level of 95% confidence interval.

$$\text{Order placement} = \text{IF THEN ELSE (MODULO (Time, } I_{RP}) = 0, 1, 0) \quad (13)$$

The cost of placing the order (O_C) depends on the processing cost, order rate, etc., and is defined using Equation (14).

$$O_C = \text{IF THEN ELSE } (O_R > 0, OP_C, 0) \quad (14)$$

where OP_C is the cost of processing one order in SAR.

Finally, the cumulative cost (C_c) is computed using Equation (15). It is the total cost (T_c) of ordering the inventory, and it includes the item cost, holding cost, order cost, etc.

$$C_C = \text{INTEG}(T_C, 0) \quad (15)$$

where T_C is the total cost and is the aggregate of holding (H_C) and ordering (O_C) costs.

4. Results and Discussion

The objective of this work is to assist a hospital inventory manager in choosing the optimal inventory policy from the list of available options. The inventory model is developed using the hospitalization percentage derived for KSA using the SEIHI$_s$RS model developed in [35]. The question is, does the inventory manager change their inventory management and ordering policies from time to time to align with the government policies to curb the pandemic? Or do they follow a rigid and conventional approach. It is obvious that the decision-making is based on total inventory cost. Considering the dynamics of government policies and the variation of future infection rates, an attempt is made to justify the selection of an inventory management policy for a selected hospital in KSA during the pandemic. Government isolation policies and the daily infected population have the biggest impacts on the load in hospitals during pandemics, which indirectly affects stress and the count of mortalities.

During the pandemic, any hospital has to maintain an inventory of multiple items. These items are either available locally or internationally. However, considering the severity of the disease, one should have to manage the inventory. The different situations as shown in Figure 3, are experimented with the proposed Vensim inventory model to test which inventory management policy is suited. The comparison is done based on the periodic cumulative cost of inventory and the flow pattern of inventory.

4.1. Inventory Management Cost under the Influence of Different Lockdown Plans

The three lockdown policies WLD, PLD, and FLD are considered to be appropriate to test which inventory policy is better or to be dynamically adopted.

From the following Figure 4, it can be observed that for WLD government policy during the pandemic, the hospital inventory manager can rank the inventory policies for a given item. The optimum cost policy is the best inventory policy. Here it is evident that the JIT policy is the best during no lockdown.

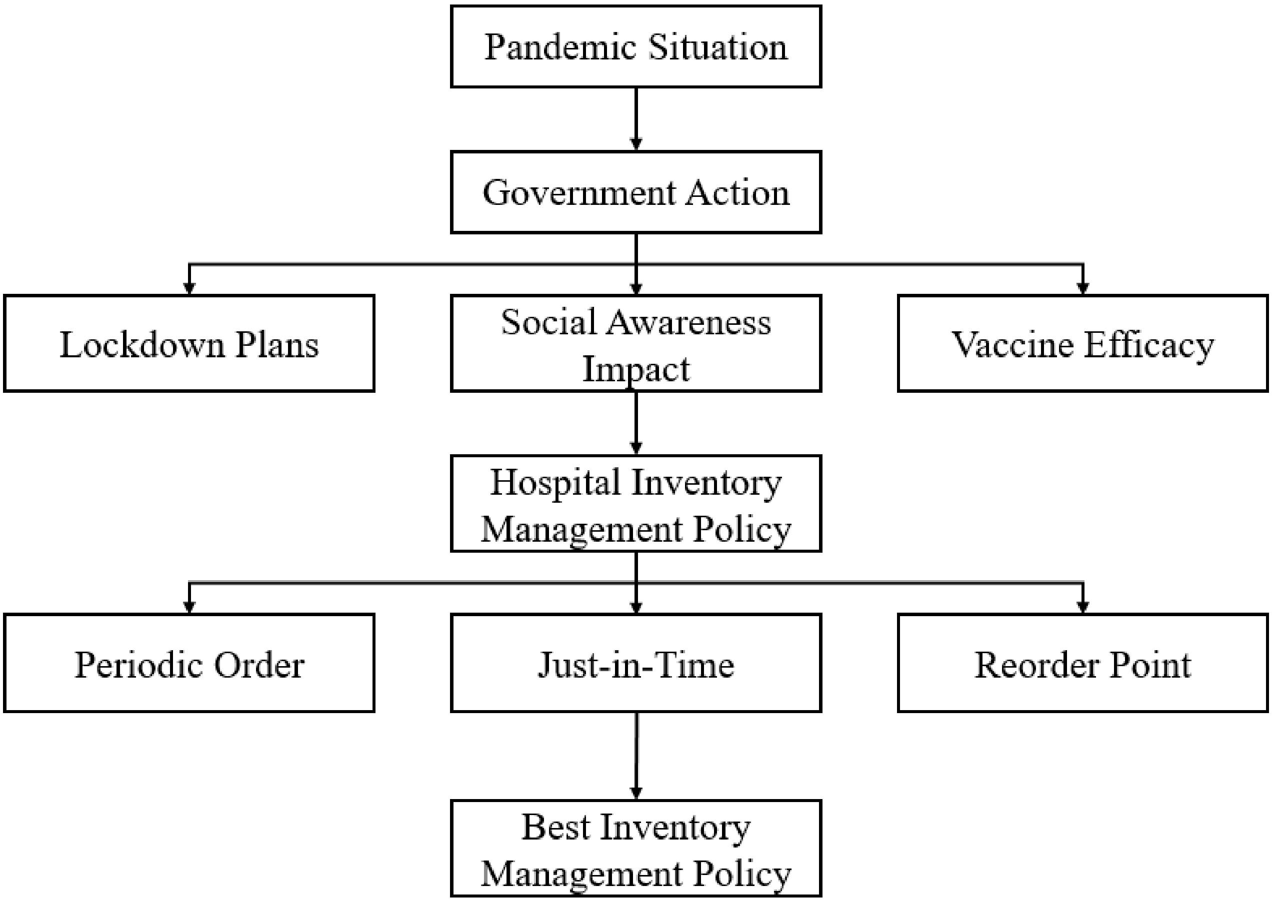


Figure 3. Flow chart representing the various situations.

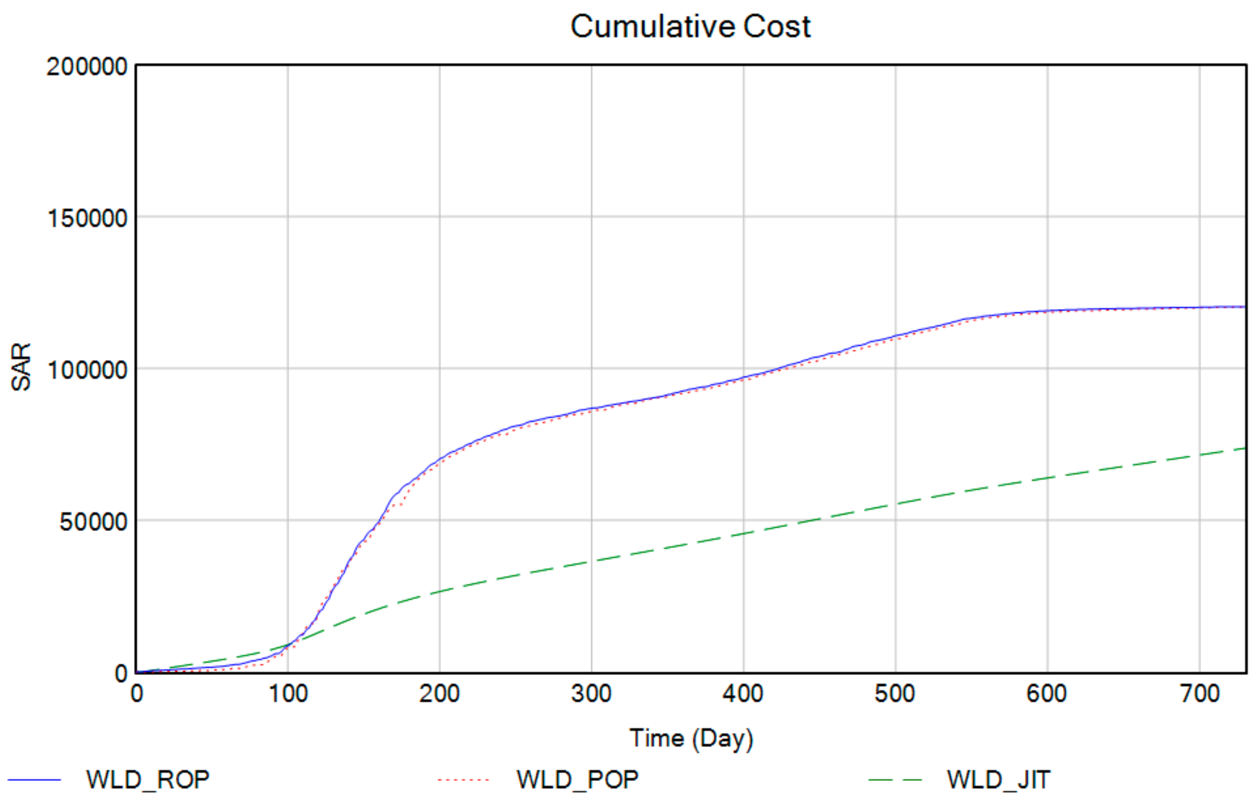


Figure 4. *Cont.*

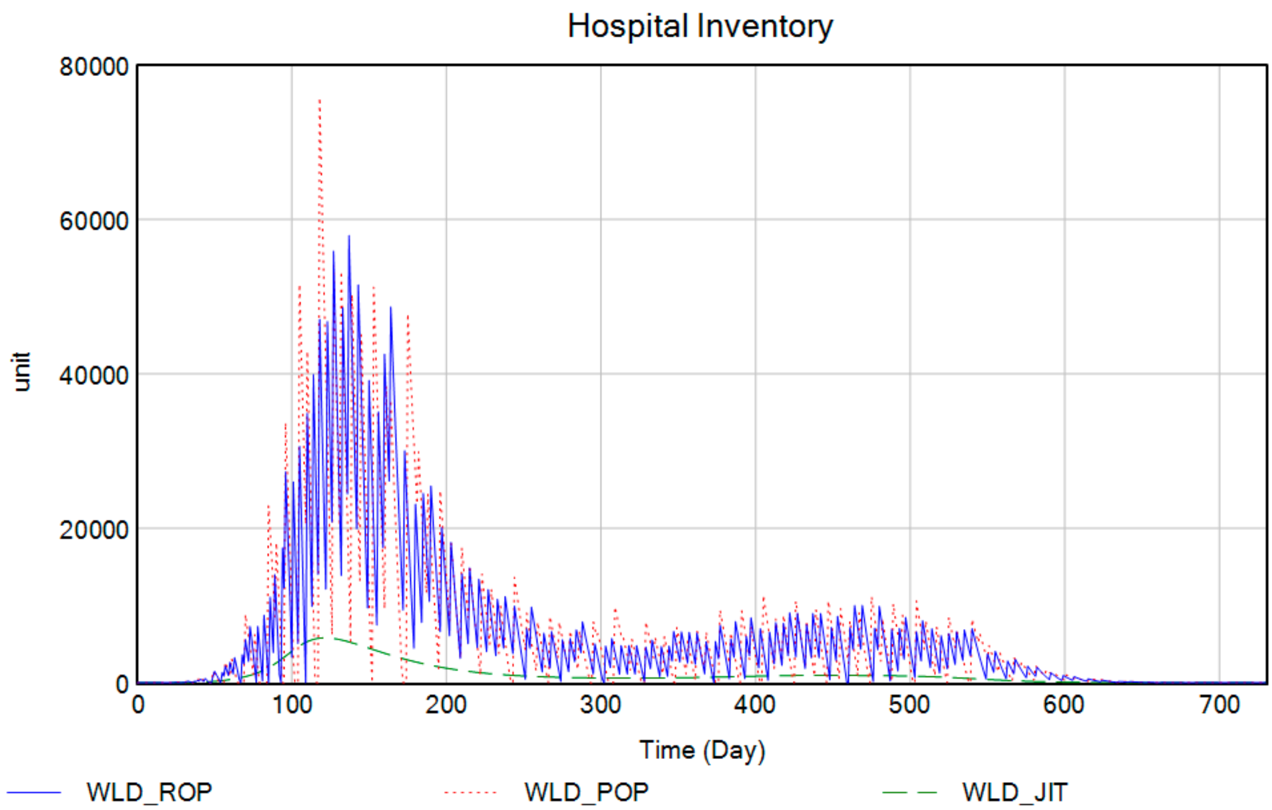


Figure 4. Comparison of inventory policies during WLD.

Subsequently, as the pandemic grows, the government tries to adopt PLD, in such cases, there will be too much control on the supply chain, and it will also impact cost. So, when PLD is implemented or going to implement, the inventory manager has to change his/her policy accordingly. It is evident from the following graph (Figure 5) that the JIT is still better in PLD.

However, in the long run, as the pandemic grows to peak, governments are forced to adopt FLD, in such cases, there will be heavy disruption in the supply chain and difficulty to manage the demand on time. So, when FLD is implemented or going to implement, the inventory manager has to change his/her policy accordingly. It is evident from the following graph in Figure 6 that POP policy is best and the cost of inventory is reduced by five times. It is also evident that if managers go with JIT he/she can opt for it with the same inventory cost, i.e., 60K, but implementing JIT during full lockdown is very difficult, so it should be preferred to opt for POP with a five times reduction in inventory cost.

ROP and POP techniques behave quite differently during lockdowns from JIT inventory management. Due to pandemic response, behaviors, and mobility restrictions, demand for some hospital inventory products may change considerably during lockdowns. Because ROP and POP may find it difficult to adapt to these changes soon enough, the inventory levels may become unpredictable or chaotic. JIT inventory management, on the other hand, is made to be more responsive and rapid to change. Moreover, disruptions in supply chains during lockdowns significantly influence inventory management strategies. Thus, JIT due to its reliance on shorter lead times and smaller inventory buffers is better equipped to manage these disruptions. So, it is crucial to thoroughly weigh the advantages and disadvantages of each strategy before putting it into practice. Thus, Table 3 summarizes how different lockdown measures and inventory management methods affect the overall cost of managing the hospital's inventory. It is evident from Table 3 that JIT is the optimum inventory strategy for WLD and PLD, while POP is best for FLD.

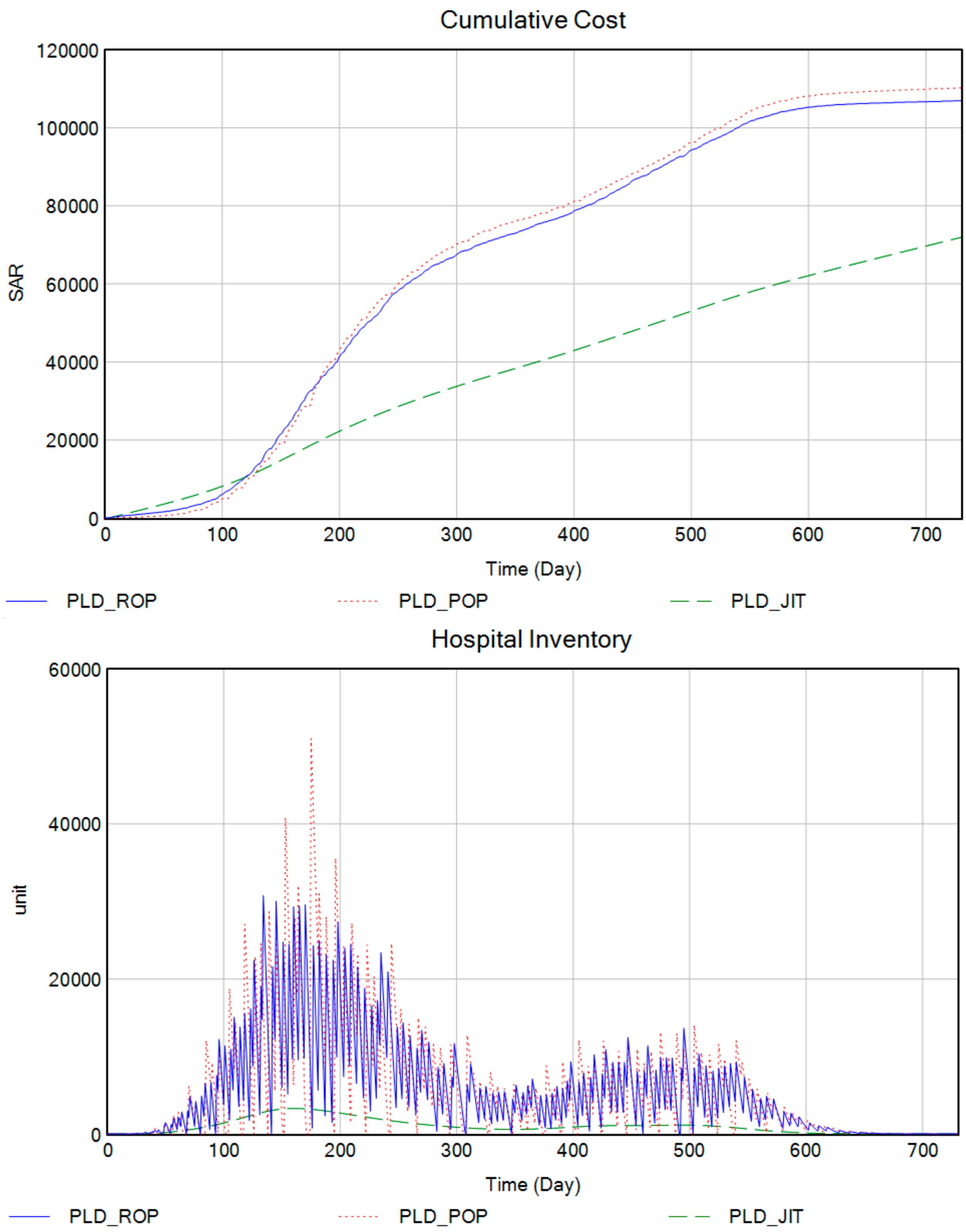


Figure 5. Comparison of inventory policies during PLD.

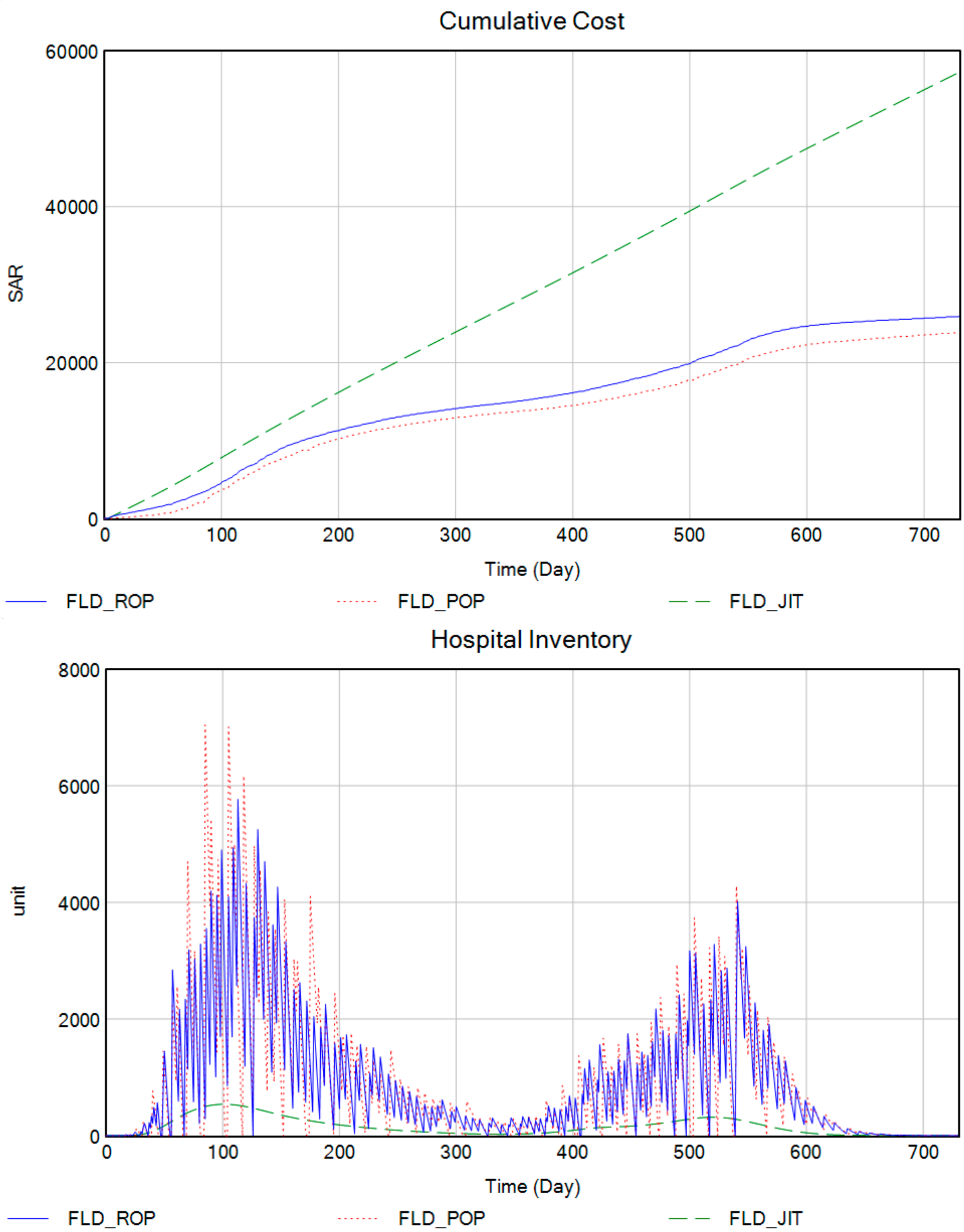


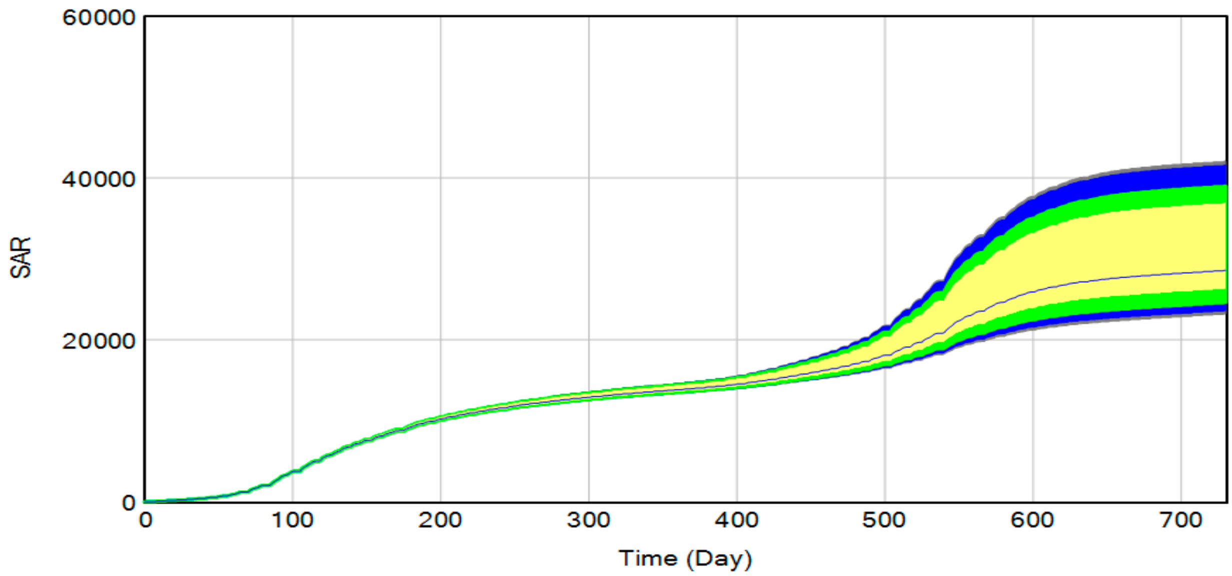
Figure 6. Comparison of inventory policies during FLD.

Table 3. Total inventory management cost.

Lockdown Strategy	Inventory Policy		
	ROP	**POP**	**JIT**
WLD	120,363	120,287	73,762
PLD	106,886	110,225	71,939
FLD	25,946	23,888	57,246

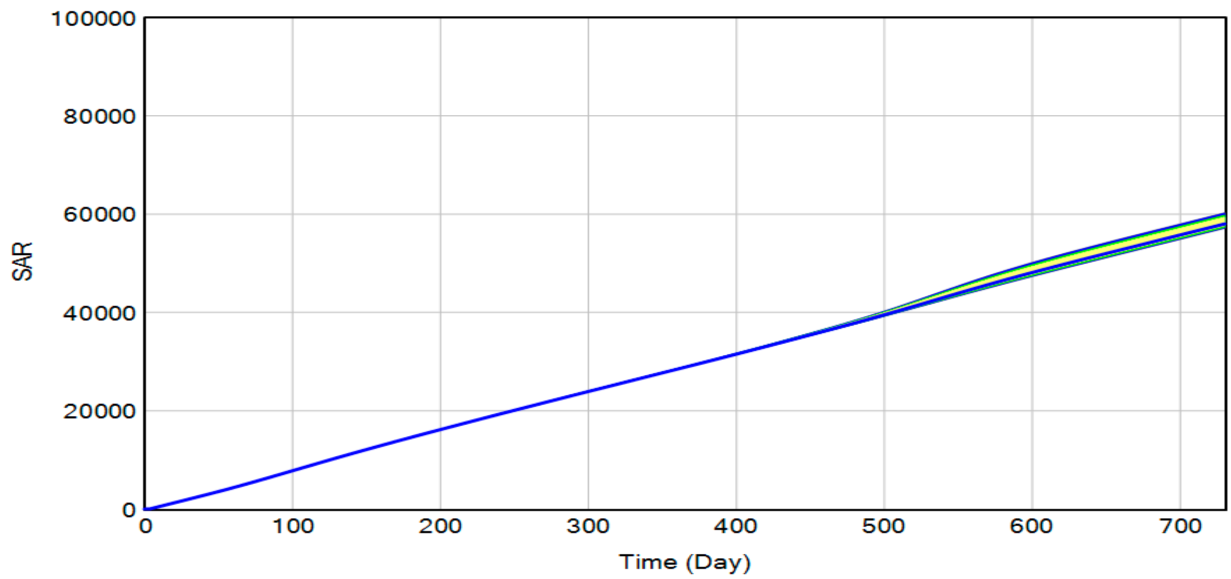
4.2. Inventory Management Cost under the Influence of Social Awareness Impact

Effective inventory policies have been explored here according to social awareness in society. The uncertainty in the total cost of inventory management as it varies over time when social awareness impact is uncertain between low and very high is shown by the sensitivity graph in Figure 7. At any given time, 50% of the simulations have produced a result that falls within the 50% range, 75% within the region, and so on. The model's results demonstrate a modest amount of uncertainty in the total cost of inventory management related to the value of societal awareness impact. Under the policy POP and ROP, refer to Figure 7a,c, it is obvious that in the first year, uncertainty in total cost is still low, but it gradually increases in the second year as a result of the cumulative nature of the total cost of inventory management. In the case (refer to Figure 7b) of inventory policy JIT, uncertainty in total cost remains very low, while the total cost for inventory management remains high. Figure 7a,c show that the overall cost for inventory management is distributed with something resembling a bell-shaped curve, although a uniform distribution of uncertainty input of social awareness impact is utilized. Furthermore, the use of PPE in hospitals is affected by a combination of several different independent variables in this model. Efforts must be made to raise social awareness in the public and minimize the burden of hospital inventory management.

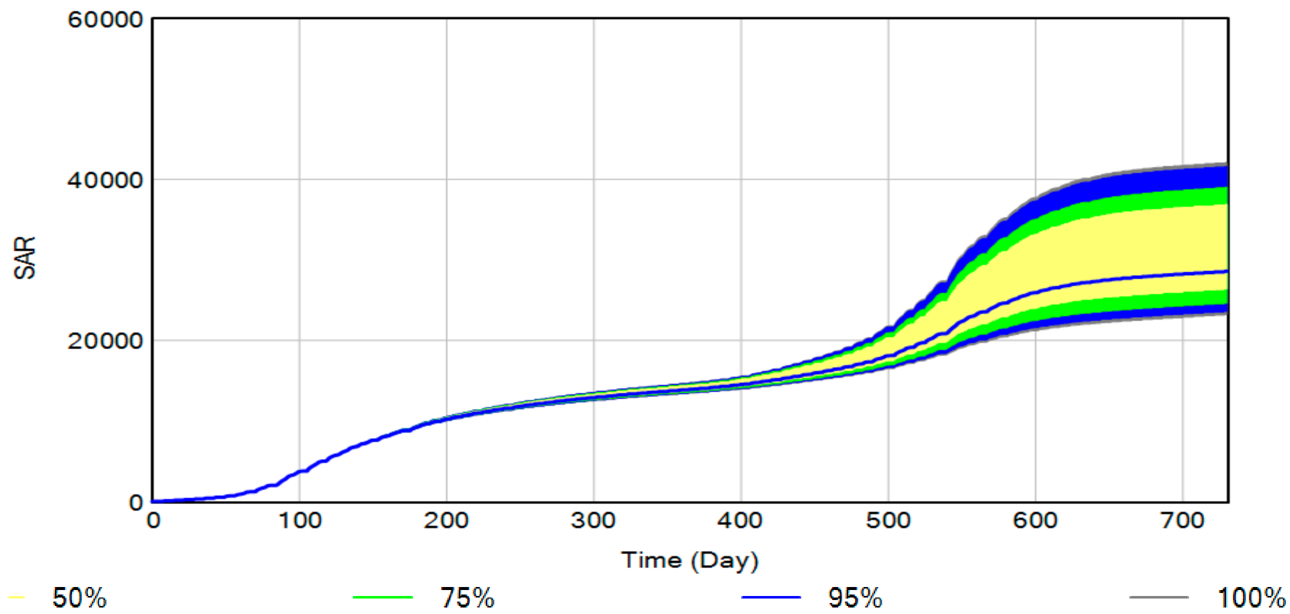


(**a**)

Figure 7. *Cont.*



(**b**)

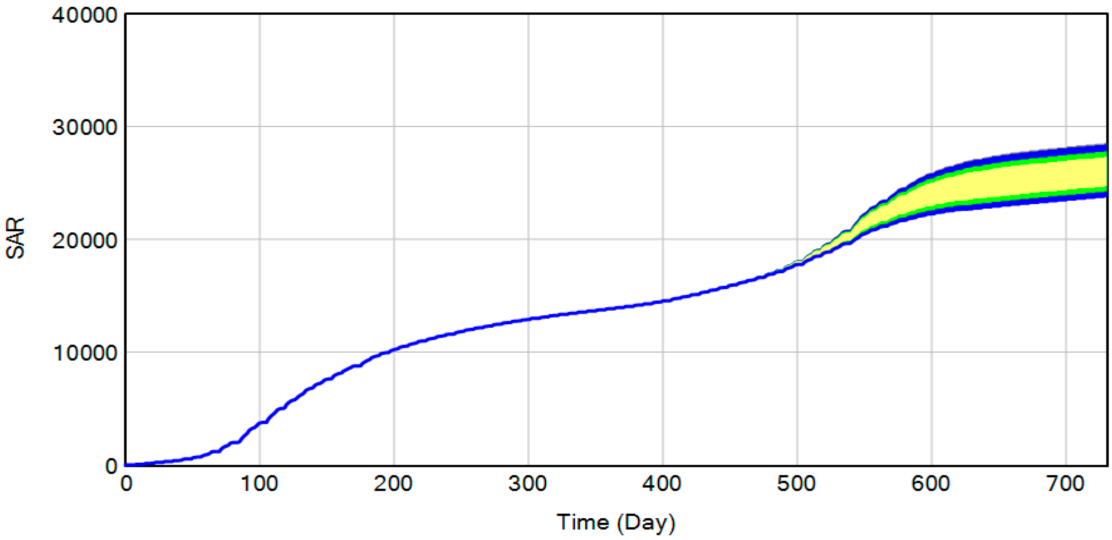


(**c**)

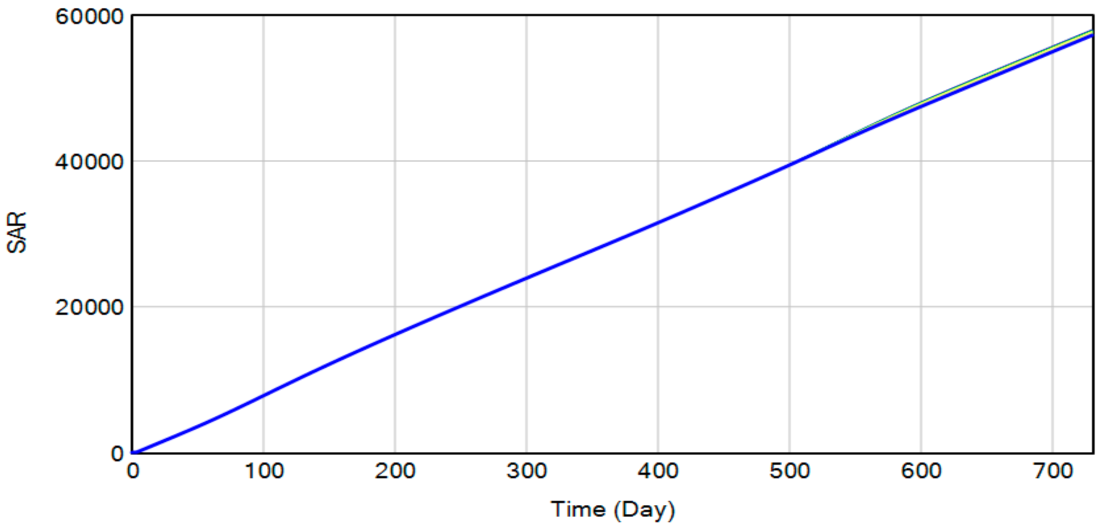
Figure 7. Total inventory management cost sensitivity graphs under the influence of social awareness impact for policies (**a**) POP (**b**) JIT and (**c**) ROP.

4.3. Inventory Management Cost under the Influence of Vaccination Efficacy

In order to decide effective inventory policies according to vaccine effectiveness around the hospital sensitivity study has been done and presented herewith in Figure 8. The uncertainty in the total cost of inventory management as it varies over time when vaccination efficacy is uncertain between low, medium, and high is shown by the sensitivity graph in Figure 8. The model's results demonstrate a negligible amount of uncertainty in the total cost of inventory management related to the value of vaccination efficacy because the influence of the vaccine on the COVID-19-infected population is visible only after nine months. Under the policy POP and ROP, refer to Figure 8a,c, it is obvious that in the first year, there is no uncertainty in total cost, but it closely increases in the second half of the second year, this evident as a result of the availability of vaccine in the second year only. In the case (refer to Figure 8b) of inventory policy JIT, there is no uncertainty in total cost, while the total cost for inventory management remains higher than other policies.



(**a**)



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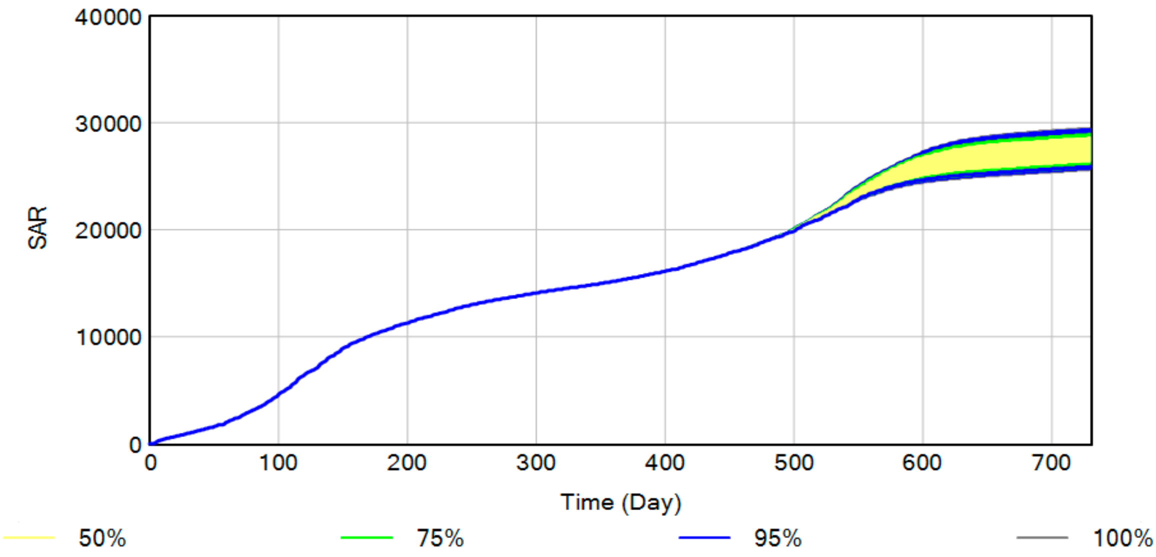

(**c**)

Figure 8. Total inventory management cost sensitivity graphs under the influence of vaccination efficacy for policies (**a**) POP (**b**) JIT and (**c**) ROP.

5. Conclusions

The necessity of efficient healthcare inventory management is one of the many insights the community has gained from the COVID-19 catastrophe. The lack of medical resources for individuals in need is the primary reason for many fatalities worldwide. Thus, it is crucial to simulate the demand for desirable medical commodities at the appropriate time in order to prevent the propagation of COVID-19. This research has looked at different inventory policies such as reorder point, periodic order, and just-in-time in order to reduce the aggregate pandemic cost for goods like pharmaceuticals, vaccines, beds, etc.

The just-in-time inventory policy is found to be the most cost-effective when there is no lockdown or only a partial lockdown when various inventory policies are assessed for various lockdown plans. This is because less wastage and reduced overstocking reduce the overall cost of the inventory. Furthermore, due to unrestricted movement during no lockdown or partial lockdown, the desired item could be readily available when it is needed. Therefore, it is inappropriate to maintain a stock of medical supplies because practicing this could result in excessive cost increases due to wastage and holding. Full lockdown, on the other hand, would cause significant supply chain disturbance and make it challenging to meet demand on time. Therefore, when there is a complete lockdown, the periodic order policy is the best inventory policy since it would result in the lowest cost of inventory management. The cost of inventory management, however, does not appear to be moderately influenced by the impact of social awareness. It is obvious that greater inventory is needed as public awareness grows. According to the analysis, periodic order and reorder policies are cost-effective strategies to apply when social awareness is high; however, with JIT, the overall cost of inventory management is high. Furthermore, it can be deduced that periodic order and reorder policies are the best inventory strategies for uncertain vaccination efficacy, especially in COVID-19's later stages. There is more uncertainty due to the increased availability of vaccines, thus it is preferable to maintain a supply in advance.

This work will help establish the best healthcare inventory management systems in order to guarantee that the appropriate healthcare requirements are accessible at the lowest cost. Using the results of this study, appropriate regulations and actions can be implemented to reduce the expense of the COVID-19 virus's possibly dangerous effects.

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