

# **An Approach for Optimization of Medical Logistics Operations Associated with the Military Using M&S on a Cloud Environment**

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## ABSTRACT

Military logistics may be defined as the discipline of the planning and subsequent implementation of the movement of military supplies (and forces). Military logistics is a broad spectrum term that is associated with many aspects of military operations. The focus of this paper will be upon medical logistics in the military. In this paper, an analysis of the supply of medical supplies (including pharmaceuticals, equipment and medical personnel) to a field hospital during the time of a military operation has been carried out. The rate at which the supplies arrive at the facility and the rate at which they are used up, thereafter, has been measured and recorded, thereby enabling a model for the existing system to be established. Bottlenecks associated with the system have been identified in the instances when there arose a shortage of these said supplies. Having modelled the existing system, its shortcomings have been identified, thus making it possible proceed with the optimization of the system via the use of a simulation tool that runs on a Cloud environment. The supply rate of medical equipment (namely pharmaceuticals and medical apparatus) and the schedule of the medical personnel deployed in the military base have been optimized.

## INTRODUCTION

Military logistics is an umbrella term that encompasses the planning and, eventually, the implementation of the movement and the maintenance of military supplies – and forces, for that matter. The operations that are involved in military logistics include: the design, acquisition, development, maintenance, storage and distribution of materiel (the supplies and equipment in the military supply chain), the transportation of personnel including troops and doctors, subcontracting and the acquisition and provision of external services and facilities, and medical and health service support – which is the branch of military logistics that we are concerned with in this paper. Medical logistics in the military is concerned with the logistics of medical supplies which include pharmaceuticals, medical devices and equipment as well as medical staff such as nurses and doctors.

According to Galuszka (2006), medical logistics in the military is a “broad and complex field” that is often the “most difficult logistical function to perform.” Medical logistics is unique and contrasts starkly to other fields of logistics in that it seeks to maximise effectiveness rather than efficiency. This is due to the fact that the final customers – who, in this case study, is the military – are responsible for ensuring the well-being of their patients – who, in this case study, are themselves the soldiers who sustain injuries during times of war. Medical logistics in the military domain does not support major concepts that are featured in more conventional supply chain models and practices. Whereas most conventional supply chains have adopted the just-in-time (JIT) philosophy which places emphasis upon holding little or no inventory, medical supply chains – and especially those in the military domain – hold that keeping large amounts of inventory is an acceptable practice due to the high costs that are incurred when stock-outs occur.

When stock-outs do occur, harm is inflicted upon the patients who arrive at the military's medical facilities and who, subsequently, are unable to benefit from the medical supplies that they would otherwise have been able to had the stock-out not occurred. Such stock-outs take a toll on the well-being of these patients and, in extreme cases, can even lead to their death. Thus, the importance of avoiding stock-outs in the medical facilities of the military is evident. In order to prevent such stock-outs from occurring, the optimal levels of inventory for each type of medical supplies that are used in these medical facilities must be determined.

Several potential approaches may be used in determining these optimal inventory levels. Three potential approaches are generally recommended for solving supply chain management problems of this nature: analytic methods (such as queuing theory), physical experimentations and Monte-Carlo methods (such as discrete-event simulation) (Thierry, Bel and Thomas (2010)). However, Thierry, Bel and Thomas (2010) assert that the use of analytic models is "generally impractical" because the mathematical models involved are often "too complex to be solved" and that the use of physical experimentations "suffers from technical- and cost-related limitations). In fact, they imply that "a modeling and simulation approach is the only practical recourse" (Thierry, Bel and Thomas (2010)).

## IMPLEMENTATION

In this paper, an analysis of the supply of medical supplies (including pharmaceuticals, equipment and medical personnel) to a field hospital during the time of a military operation has been carried out. This is essentially a medical logistics problem within the military domain. As advocated by Thierry, Bel and Thomas (2010), a modelling and simulation approach will be employed to solve the inventory problem at hand. Specifically, simulation-based optimisation will be utilised. This approach, initially, entails that the modelling and simulation of the existing system at the field hospital be carried out, before alternative solutions, in which some of the original parameters are altered, are generated, among which an optimal solution will be chosen.

The parameters that have been altered during this study were the staffing levels (the number of doctors, nurses and technicians present at the field hospital during different times of the day) and the re-order point of each type of medical supplies that are used in treating the patients who arrive at this field hospital. Essentially, the aim of this study is to find the optimal staffing schedule and the optimal re-order point required (and essentially the safety stock of each class of medical supplies that must be kept) to ensure that stock-outs – that could potentially have an adverse effect upon the well-being of the patients – do not occur.

This simulation-based optimisation will be carried out using simulation-based decision support tool called *SimBusPro*, which was developed by *Simsoft* as part of an EU-funded project by the name of *Sci-Bus Scientific Gateway Based User Support (SCI-BUS)*. This software was preferred due to its ability to carry out simulations and optimisations on the Cloud. This feature allows it to run simulations and generate alternative solutions (leading to the identification of optimal solutions) at an unprecedented rate. Another prominent feature of *SimBusPro* is that it makes use of the latest version of the universally-recognised Business Process Model and Notation (BPMN 2.0) as its modelling standard.

## RELATED WORKS

During a military operation, personnel injuries are unavoidable and therefore must be treated swiftly to diminish negative impacts such as loss of manpower and morale. The cost of an injury could be tremendous when its treatment is not completed on time and therefore reducing waiting times in medical centres is a must for the management of such systems. Waiting times are mostly related to scarce resources such as service provider personnel (e.g. doctors and nurses) and material (e.g. medical devices and consumable medical goods).

Militaries have often tried to incorporate commercial practices in an attempt to manage their supply chain and to "lean-out their inventory practices and make their logistics operations more efficient" (Hester(2009)). In their quest to improve their logistics operations, militaries have attempted to adapt the JIT philosophy only to find that this philosophy was perhaps not the best suited to respond to the requirements of medical logistics in the military domain. Hester (2009) relays that, "JIT has shown to work well for many applications, but ultimately results in a brittle supply chain that has a high risk of failing in a dynamic environment."

Waiting lines in health care context has been a popular issue for many years. It is dealt in conventional queuing theory context such as in Worthington (1991) and Zonderland and Boucherie (2012). In a wider context, patient flows incorporate theory with practice. Harper (2002), Vissers and Beech (2005) and Hall et al (2006) provide frameworks for modelling patient flows in health care facilities and the logistics of medical supplies.

Simulation has been a popular modelling method in health care domain. Particularly Discrete Event Simulation (DES) attracted considerable attention as the literature reviews suggest (Gunal and Pidd (2010) and Katsaliaki and Mustafee

(2011)). Other than discrete-event, there are other simulation techniques such as System Dynamics and Agent-Based Simulation. Gunal (2012) is a guide for using these techniques in hospitals.

Military medical centres can be seen as a mix of emergency room and outpatient clinic of a hospital in terms of patient flows and resources used. Rohleder et al (2011) is a good example of the use of simulation to improve processes in an orthopaedic clinic in a hospital.

### PROBLEM DEFINITION

We created a fictitious military medical treatment centre which mainly handles two types of injuries; Broken bone (I1) and open wound (I2). Each type requires some certain amount of supplies of medical goods for the treatment of injuries. We can associate material requirements using a table such as below (Table 1). Note that such tables essentially come from medical practice and are not explicit. While medical staff (e.g. doctors and nurses) treat patients, they consume materials as required based on their experience but also considering medical best practices.

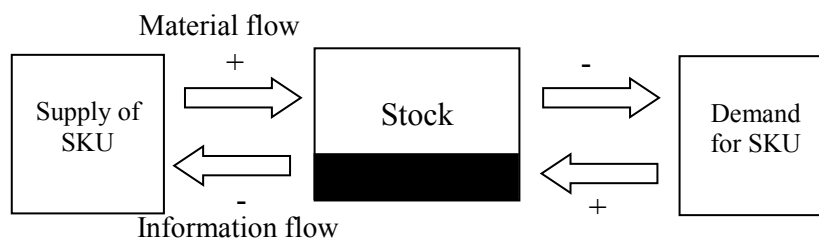
In this fictional case, we simplified the reality since an injury hardly requires only two types of materials. For example, Zambraski and Yancosek (2012) found that most injuries are Musculoskeletal Injuries (MSIs) in military and their treatment requires more than 20 types of medical supplies. In our case, as an MSI, an I1 case requires 2 SKU1s and 1 SKU2. “SKU” means “Stock Keeping Unit” and a standard logistic terminology. Case and supply matching is not necessarily one to one, since an SKU might be used in multiple cases. In table 1, SKU2 is used in I1 and I2.

Table 1: An example of medical cases vs. supply requirements

Medical Case	Required	
	Material	Amount
Broken Bone (I1)	SKU 1	2
	SKU 2	1
Open wound (I2)	SKU 2	4
	SKU 3	2

An inventory system, including our fictitious medical treatment centre, which holds SKUs can be seen as a pool; Supply of SKUs fill the pool and Demand for SKUs empties the pool (Figure 1). The difference between Supply and Demand is stored as stock. Although keeping stocks is costly and not desired, when the demand and supply do not match and unpredictable, keeping safety stock is a must to avoid out of stock. There are two types of flows in an inventory system; Material flow and information flow (Figure 1). Material flow is the physical flow of goods. Goods flow from supplier and increase the stock, and consumers (the demanders) deplete the stock. The information flow is on the opposite way. The demand side sends signals to stock management to make the stocks increase (the plus sign below the arrow between Demand and Stock), and the stock management asks the supplier to produce more.

Figure 1: A simple inventory system.

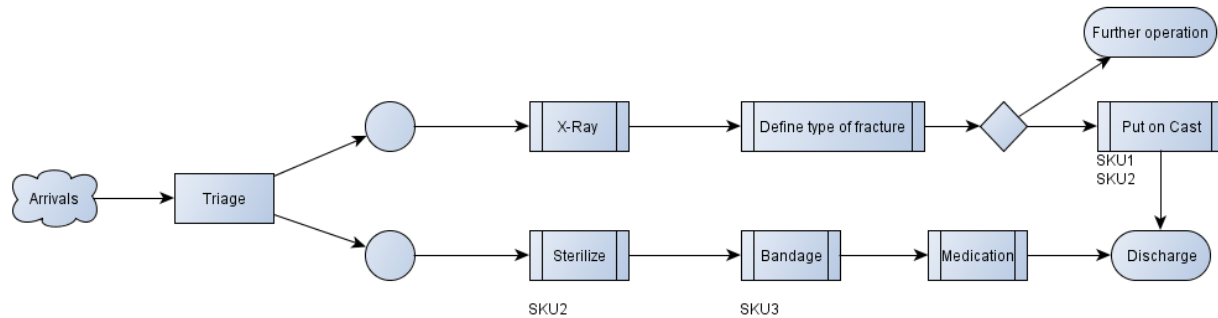


The basic inventory system flow in figure 1 is embedded in processes of a system. In our case, we created a flow diagram in figure 2 to model patient flows in the medical centre. In this diagram, consumption of SKUs are shown below processes. Arrivals to this system are stochastic and assumed to follow exponential distribution with a mean of 10 cases per month for I1 and 20 cases for I2. A case is first triaged to assess the severity level and to determine the type of treatment.

In I1 cases, X-Ray is taken first. This process is a time consuming process which requires an X-Ray machine. X-Ray machines are generally shared resources in hospitals and therefore waiting for X-Ray is likely. We assume that, including transfers, X-Ray process time is log-normally distributed with a mean of 40 minutes and a standard deviation of 10 minutes. The doctor will assess the X-Ray and determine its type. If it is not requiring further operation such as locating metal pin, the patient is forwarded to put on cast process. This is where SKU1 and 2 are required in the amounts given in table 1.

In I2 cases, the wound is first sterilized using SKU2 and later the bandage is put on. This case is fairly simple compared to I1. After prescribing medication the patient is discharged.

Figure 2: Patient flows in the medical centre.



The information related to the task times and the resources in the system are given below.

Table 3: Total number of resources in the system.

Resource	Quantity
Doctor	1
Nurse	1
Technician	1

Table 4: Task times and resources they used.

Task	Process Time Distribution (minutes)	Resources Used
Triage	Triangular(1,3,10)	Nurse
X-Ray	Normal (10, 15)	Technician
Diagnosis	Normal (5, 10)	Doctor
Puton Cast	Normal (10, 40)	Nurse
Sterilise	Normal (5, 10)	Nurse
Bandage	Normal (10, 20)	Nurse
Medication	Triangular (1, 5, 10)	Doctor

The process illustrated in Figure 2 essentially represents the Demand in Figure 1. The amount of SKUs consumed is related to the stochastic patient arrivals. Note that patient arrivals are subject to variation and therefore stock planning of SKUs must take the patient arrival variation into account. In the supply side, there are two key questions; how many SKUs to supply, and when to supply. Should the management of the treatment centre order supplies frequently in small quantities, or should we order supplies less frequently in larger batches? These two questions are significantly important when the SKUs have shelf life. In the latter case, for example, when we supply big batches and if there is not enough demand, then we can face out-of-date and unused SKUs.

In this study we examined the effects of patient arrivals on the supply policies of SKUs as presented in Table 2. We created four scenarios. In Scenario 1, we assumed that all three types of SKUs are supplied to the medical centre 20 items per month. In Scenario 2, the amount is increased to 40 items per month. In other two scenarios, the amounts are kept the same but frequency is decreased to two months.

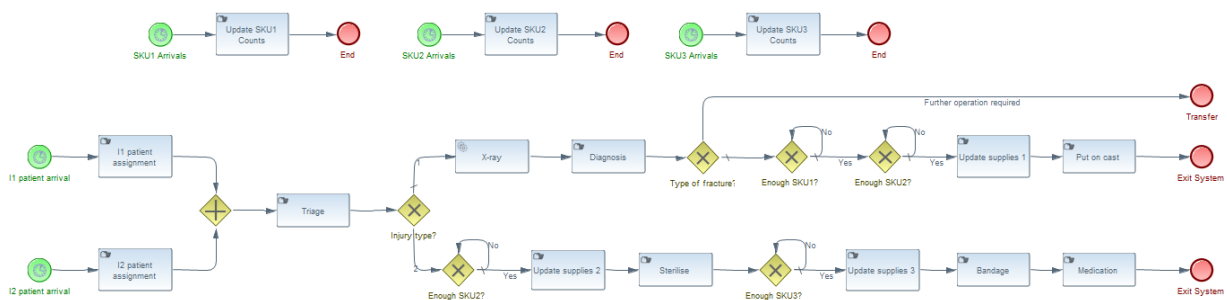
Table 2: Scenarios for different supply policies.

Supply Policy	SKU 1	SKU 2	SKU 3
1	20 per month	20 per month	20 per month
2	40 per month	40 per month	40 per month
3	20 per two months	20 per two months	20 per two months
4	40 per two months	40 per two months	40 per two months

### THE SIMULATION MODEL

We built a model using *SimBusPro* (SBP) wherein the flow diagram illustrated in Figure 2 was translated to a BPMN diagram as shown in Figure 3. SBP has three basic building blocks for modelling: events, tasks, and gateways. The upper part of figure 3 is dedicated to the three different types of inventory arrivals (SKU 1, SKU 2 and SKU 3) whereas the lower part is dedicated to the flow of the patients and the processes that they subsequently undergo in the medical facility. The inventory arrivals are simulated via the use of start events which act as generators which trigger the increase of each type of inventory at predetermined times. For example, for Supply Policy 1 (see table 2), the model generates arrival of inventory of type SKU 1, SKU 2 and SKU 3 once every month and increases each stock level by 20 items.

Figure 3: Medical Centre's BPMN diagram in SBP.



The patient flow in Figure 2 is elaborated in the BPMN diagram. We created a start event for each patient type (I1 and I2). Since the triage is common for both types, the flows of the patient entities are merged using a parallel gateway. After

the triage, as in reality, the patients are sent on their own paths depending on their injury type, which is achieved using an exclusive gateway.

The I1 patients are sent to be X-rayed, after which their diagnosis can be made. The X-ray is performed by a technician whilst the diagnosis is made by the doctor in the medical centre. The type of fracture that the I1 patient has is determined during the diagnosis. If the I1 patient is found to require an operation, he is transferred outside the medical centre so that it may be carried out in a more appropriate facility. If not, the I1 patient must be put on a cast. However, before this task can be carried out, it must be made sure that there is enough SKU 1 and SKU 2 currently present in the system to carry out those task (because this task requires 2 units of SKU 1 and 1 unit of SKU 2 to be present in the system). This is carried out using two exclusive gateways. The first checks if there is enough SKU 1 available, whereas the second checks if there is enough SKU 2 available. When a token arrives at the first gateway, if the quantity of SKU 1  $\geq 2$ , then there is enough SKU 1 available to fulfil the task, and the token can pass onto the second gateway. Otherwise, the patient token is sent on a loop back to the same gateway where it must wait until the necessary condition becomes true. The second gateway works in the same way and the token can only pass onto the next phase if the quantity of SKU 2  $\geq 1$ . If both of these conditions are met, the token progresses onto the next task where the supply quantities are updated (the SKU 1 quantity is reduced by 2 and the SKU 2 quantity is reduced by 1). The cast is then put on the patient by the nurse, after which the patient exits the system through an end event.

The logic works in a similar manner for I2 patients. After the triage, these patients are sent to be sterilised. Once again, before this sterilisation can occur, it must be made sure that the inventory levels are sufficient to carry out this task. There must be at least 4 units of SKU 2 present in the system at the time that the patient arrives to be sterilised. A similar exclusive gateway to that used for the I1 patients is used, once again, to transfer this logic onto the model. If a patient is to be sterilised, the quantity of SKU 2 in the system is decreased by 4. After this, the patient must be bandaged (which requires 2 units of SKU 3) and then given medication. Before the bandaging operation is reached, the patient token must pass through another exclusive gateway which checks that the quantity of SKU 3 is indeed sufficient for this task to be realised. If it is, the quantity of SKU 3 in the system is reduced by 2. After the patient receives the medication, he is discharged and exits the system via an end event.

## RESULTS

The end-of-day inventory levels were evaluated for the four supply policies presented in table 2 throughout the simulation time period of a year. From inventory theory, we know that stock (inventory) levels fluctuate in a similar pattern in time depending on the demand and supply. Stocks increase as much as there is supply of goods, and generally in large amounts, and oppositely, stocks decrease by the amount of demand, but in smaller amounts. There may be two adverse effects of inventory management, in terms of the stock cycle: first, the inventory level increase linearly; second, there may be no stock at some times, which is known as a “stock-out” period.

The simulation results related to the inventory levels of each stock keeping unit are shown in Figure 4. Whilst graph (a) shows the inventory level of SKU 1 throughout the pre-defined simulation time period of one year, graphs (b) and (c) show those of SKU 2 and SKU 3 throughout the same period. In (a), all supply policies show a gradual increase in the inventory levels of SKU 1 over time. Note that in policy 1 and 2, we assumed monthly, and in policy 3 and 4, we assumed bi-monthly replenishments. The slope of each decline is the demand rate and it is the same in all scenarios. We see from this figure that the highest average inventory level is achieved in policy 2, and the lowest in policy 3. Since no stock-outs occur for SKU 1 regardless of the supply policy chosen (meaning that all patients who arrive at the medical centre will be able to receive treatment irrespective of the supply policy being used), the supply policy that incurs the lowest cost to the medical centre can be chosen as the best supply policy. It is apparent that the lowest cost will be incurred by the supply policy which achieves the lowest average inventory level over the simulation time period – which is supply policy 3.

The pattern in figure 4 (c) (for SKU 3) is similar to that that was observed in graph (a). Over time, there is a gradual increase in the inventory levels of SKU 3 for all four supply policies and, as was the case for graph (a), the demand is constant. This behaviour indicates that the inventory replenishments provide ample goods and that stock-outs do not occur, regardless of the supply policy chosen. Thus, in choosing the best alternative among the 4, the aim should be to minimise the cost incurred to the medical centre, just as it was for graph (a). As before, this can be achieved by choosing the supply policy that will minimise the average inventory level throughout the simulation time period. Therefore, supply policy 3 can be seen to be the best policy for managing the inventory levels of not only SKU 1, but SKU 3 as well.

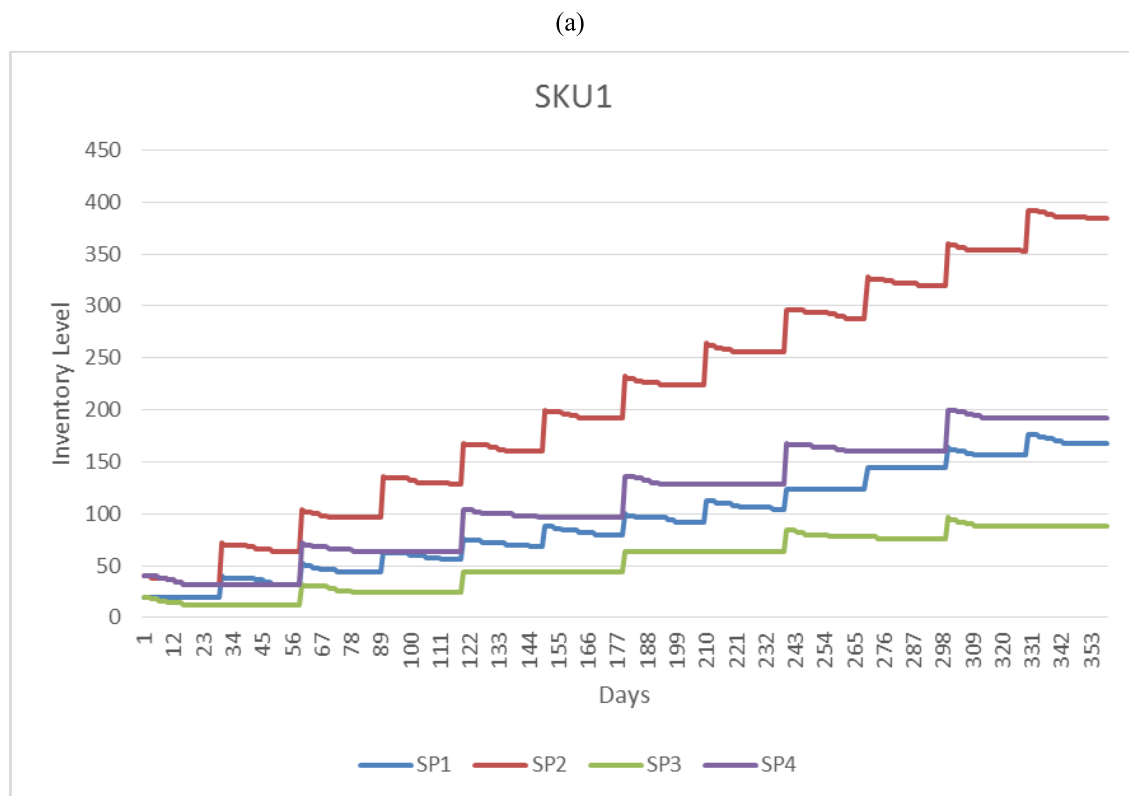
However, choosing the best supply policy for SKU 2 is not so straightforward due to the fact that stock-outs do occur for this inventory type. In graph (b), we see that a regular pattern is achieved for SKU 2 for all supply policies. As the replenishments arrive, the stock jumps up to 20 or 40 items (depending on the supply policy) and then starts to decline rapidly. From the graph, it can be seen that stock outs for SKU 2 are experienced very frequently, thus confirming that this is the stock keeping unit among the three that is used up the most in the operations in the medical centre. Due to the nature of the problem at hand and due to the fact that stock-outs do occur, choosing the best supply policy is somewhat more complex. As explained before, in most inventory problems, a just-in-time approach is desirable because the lower



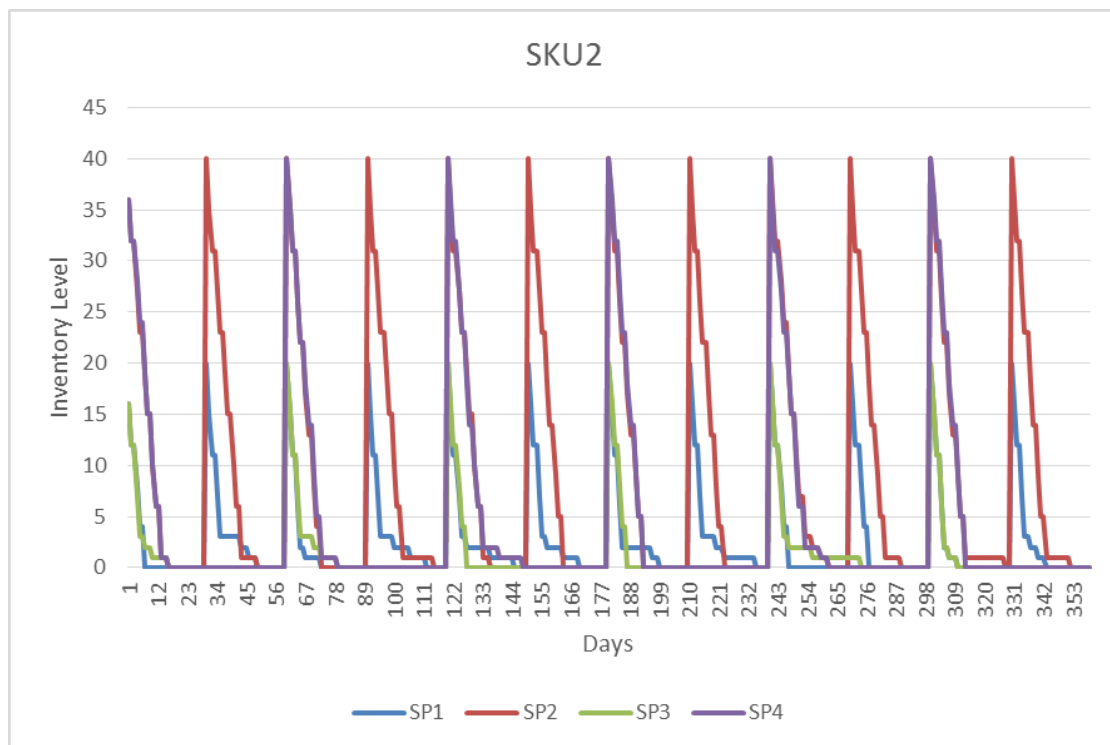
inventory levels that it creates subsequently translate to lower costs. Thus, in most supply chains, low inventory levels = low costs. However, this is not the case in medical supply chains. In medical supply chains, high levels of inventory are generally preferred because when stock-outs do occur, the cost incurred is actually higher in that harm is inflicted upon the patients seeking to receive treatment but who are unable to do so due to the lack of resources. Shortly, in medical supply chains, it is more important not to stock-out than to maintain low levels of inventory. However, for this problem, stock-outs are unavoidable regardless of the supply policy that is chosen, as can be seen in graph (c). Throughout the simulation time period of a year, stock-outs for SKU 2 occur 12 times if the replenishments are made monthly (supply policies 1 and 2) and 6 times if they are made bi-monthly. As such, the supply policy that will prolong the time-to-stock-outs must effectively be chosen as this ensures that the time during which the patients arriving at the medical centre are able to receive the necessary healthcare is maximised. Evidently, this will be supply policy that provides the highest amount of supplies. Therefore, for SKU 2, the best supply policy is supply policy 2.

By examining the demand of items in the processes in Figure 2 and table 1, the simulation results are plausible. Only two SKU 1 and 3 items are required in the I1 and I2 cases, whereas SKU 2 items are consumed at a much higher rate (almost as many as SKU 1 and 2 together). This fact explains the major difference between figures 4 (a) and (b), and figures 4 (b) and (c) for that matter. SKU 1 and SKU 3 are low-consumed items whereas SKU 2 is a high-consumed item. This system therefore requires higher quantities of SKU 2 when compared to the quantities required for SKU 1 and SKU 3.

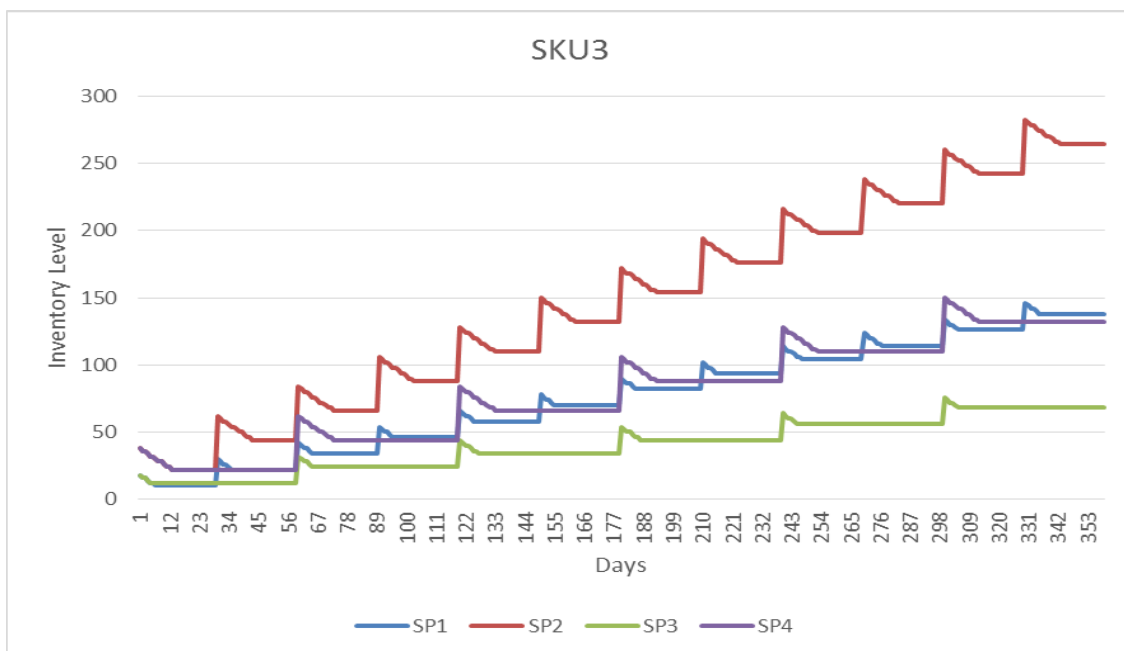
Figure 4: Simulation outputs for inventory levels.



(b)



(c)



CONCLUSION

The logistics of medical supplies in military is complex field of research that requires many problems to be solved. Simulation modelling can help solve problems in this area and assist decision-makers in making better decisions. In this paper, we aimed at creating awareness for the use of simulation in solving problems concerning decision-making in military medical logistics.

First, we defined an illustrative case study in which a medical centre treats two types of patients. Each type has a defined pathway in the medical centre. Patients interact with human resources in the processes and consume medical goods. We fictitiously assumed the amount of goods used in each process. This assumption is the base for the demand function of



goods. Additionally, we created four alternative scenarios of supply policies. We altered the replenishment period (monthly and bi-monthly) as well as the quantity of the supplies.

We evaluated one performance indicator: the change in the inventory levels of each stock keeping unit throughout the course of a year (the simulation period). Time series graphs of the simulation results showed that the inventory levels for SKU 1 and SKU 3 increase steadily for all supply policies, whereas SKU 2 moves periodically and experience stock-outs. These observations are plausible to users since the demand for SKU 2 is much higher than the demand for SKU 1 and 3. Since SKU 1 and SKU 3 never stock-out, it is then viable, in determining the best supply policy for these two stock keeping units, to choose the one that will create the lowest inventory levels (and so, incur the lowest cost), which is supply policy 3. However, stock-outs are unavoidable and do indeed occur for SKU 2 no matter which supply policy is chosen. What is more is that since the time at which the replenishments occur is either monthly or bi-monthly, the number of stock-outs that occur is fixed and pre-determined by the frequency of the replenishments. Thus, in determining the best supply policy for SKU 2, it is unwise to choose the one that yields the lowest inventory levels as this would have a detrimental effect upon the well-being of the patients who arrive at the medical centre. Thus, the policy which keeps the length of stock-outs at a minimum must therefore be chosen for this stock keeping unit. This, it goes without saying, is the supply policy which provides the highest inventory levels because it will take a longer time for these larger quantities of inventory to be used up and stock-out. Therefore, the best supply policy for SKU 2 is supply policy 2.

This now appears to leave us in somewhat of a predicament in that two different supply policies have been found to be the best for the three different stock keeping units. Whereas supply policy 3 has been found to be the best for SKU 1 and SKU 3, supply policy 2 has been found to be the best for SKU 2. So now, the following question must be answered: what is more important: maintaining low levels of inventory or maximising the number of patients that are able to receive care? If this were any other supply chain problem (besides medical), then importance would have been placed on minimising inventory levels due to the fact that this would then minimise costs. However, in this case, to minimise inventory levels would be to jeopardise the well-being of the patients who arrive at the medical centre. Essentially, at low inventory levels, stock-outs occur more rapidly and fewer patients are able to receive the necessary treatment, meaning that their health is adversely affected. The cost of this is much higher than the cost of keeping high inventory levels. In conclusion, if only one supply policy has to be chosen for all of the stock keeping units, it would be wise for the management of this medical centre to choose supply policy 2.

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