Evaluation of nonlinear system behaviors in Military Supply chain

S.K. Bhagavatula, J.C. Chedjou, K.R. Anne, K.Kyamakya
Institute for Smart Systems-Technologies
University of Klagenfurt
Klagenfurt, Austria

***Abstract*—This paper discusses the concepts of military supply chains and make comparisons with commercial supply chains. After an introduction, the major observations concerning military supply chain deficiencies like unmanageable demand forecasting are addressed. Furthermore, the uncertainties and invalid priorities in military inventory operations are described. Further considerations do examine the required optimization models and analyze both the product and information flows during warfare in military supply chains. Finally, a new model which withdraws the nonlinear system behaviors in military supply chain is suggested.**

***Keywords*—Military Logistics, Military Supply Chain, Inventory visibility, Nonlinear System Behavior.**

I. Introduction

Supply chain management is a combination of management and science. The concern of supply chain management is how firms utilize their suppliers' processes, technology and capability to increase competitive advantages. We see these supply chain networks in many sectors such as computers, toys, pharmaceuticals, automotive, consumer goods, military, etc. The formal definition of military supply chain is "All entities belonging to military or nation logistics separately, which are involved in military logistics, and network system formed by activities and interactions of the entities"[6]. Where as military has very large, complex distribution and supply systems. The basic need of military forces is to deter war and build the security to the nation. While considering the supply chain perspective/objective, in military, services are provided to prepare for warfare, not for profit. Military supply chains serve far away, always moving and have other high-risk operations in harsh conditions. In military supply chains commodities vary from every day supplies to specialized military equipments such as weapons, tanks etc. To build the same advantages, logistics management and distribution are also viewed as the key components in supply chain management (figure.1) [3].

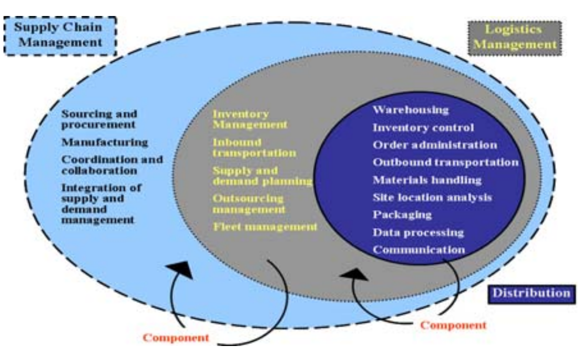

Figure.1. The relationship among distribution, logistics management, and supply chain management

At around 700 BC, a provision has made in advance to stock supplies. During this period military were employing more number of animals as means of transportation to feed and equip a force. To improve logistics and supply chain networks one initiated the soldiers to carry much of their equipment and supplies. However, in the fifth century AD armies expanded their supply chains by constructing roads, interior lines of communication and getting stock details earlier to an attack. As the centuries passed, rapid changes fall out in military operations. However, the evolved solutions are not of long duration in military supply chains.

During the Crimean war, one identified the primary courses of the warfare as logistics, supply chain, training and team coordination were recognized. At this instant one introduced the hierarchy system in military sector for provision of supply chain support. The view of administration and logistic support to the troops in the field afforded greater extent. Until this period, supplies were determined for one or two battles. When established foundations for a long war then required to uphold the supply chain between large populations with mass mobilization was necessary. To meet the majority of supplies, military tied with the railway system and keeped the operations functioning.

During the first world war, military found it difficulty to predict the demand or re-supply, when military kept on the move. One could identify cases where military people had stopped or expected to stay for long term; and such event makes consumption more than the pre-war estimates. Such unanticipated changes in the global military operations aimed to unify the supply chain networks with all military groups/hierarchical levels. At once military planners have achieved readiness on large inventories to reduce inventory on hand.[1]

During the second world war, again railways showed to meet armies' requirements. However, air and sea mode also made important contributions during this warfare. From eighteenth century onwards, the total process of the supply chain, which is making support to commercial business, is now being adapted by and adapted within the military environment. The larger and faster moving of military, the longer the supply chain became, the more difficult it became to re-supply. To defeat such aspects, initially 'Lean' and 'Focussed' Logistics were developed by the US military and acknowledged by the UK Military to support the military operations. As well one could initiate to verify the total integral stockholding and transportation systems. In addition, one extended the third party support to military operations with civilian contractors. At the end of the 20th century, military maintaines main supply bases to meet the demand and move the demand through the supply chain as required [1-2].

II. COMMERICAL VS MILITARY

The military environment is of high complexity as it uses isolated, independent and incompatible systems, processes and data. Therefore, the modeling of military scenarios is of necessary importance as models can provide in-depth explanation of the scenarios and control their occurrence and evolution in both time and space domains as well. In military, as well the supply chain management strives for qualitative changes. In commercial supply chain, a consumer's demand for a product can be changed within a period of months to acquire gain. The supply chain management conceptual models for both commercial and military are remarkably same. However, some significant differences are imparted to an evident difference in between commercial and military supply chains (figure.2). In commercial supply chains, the first issue is about absence of maintenance and another is that the flow of products/materials between suppliers and retailer, which is in unidirectional. In military supply chain the transportation, distribution/warehousing are bidirectional, that means from producer to military user and vice versa. Since military move the materials for maintenance and for medical care. The other differences are external factors including deployment of forces i.e. soldier, military regulations, joint interoperability, mission requirements [3-4].

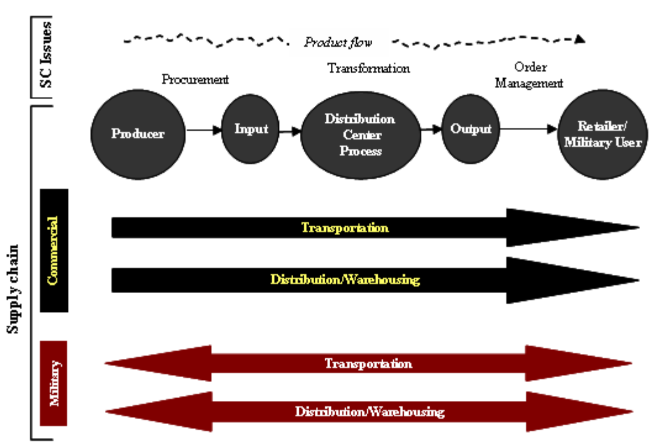

Figure.2. Commercial and Military Supply Chain Management

In commercial supply chains, people can see what is going on and they can change the business processes they have. They can take what they see and embed that into an improved method of doing business i.e. reengineering. Whereas in military supply chain, data transparency and embed into the new or improved system is an unmanageable issue because of security crisis [4]. Another major issue is concern in military supply chain is material families.

In military, materials are places in different categories as classes. It is difficult to analyze the demand issues in terms of range of supplies, movement of supplies, and reserving supplies for warfare. The resources consist of a complicated web of supplies, ranging from food and clothing to nuclear weapons. In military, inventory management must keeps records and stores the material to take the possibility of war at any moment. The necessity to store resources is to use on a daily basis as well as store resources for times of war. The military organizes all supplies into ten different classes as below (figure. 3) [7].

CLASS TYPE OF SUPPLY					
Class	Symbol		Class	Symbol	
CLASS I		Subsistence and commercially bottled water	CLASS VI		Personal demand items
CLASS II		Clothing, individual equipment, tools, administrative supplies	CLASS VII		Major end items, such as launchers, tanks
CLASS III		POL includes bulk fuels and packaged products such as antifreeze	CLASS VIII		Medical supplies, including repair parts for medical equipment
CLASS IV		Construction items, including fortification and barrier material	CLASS IX		Repair parts and components,
CLASS V		Ammunition of all types	CLASS X	CA	Materiel to support nonmilitary programs

Figure.3: Class Type of military supply

Each class consists of subclasses, which gives thorough information about supplies. The subclasses data presents as follows (fig. 4) [7].

CLASS & SUB CLASSES			
Class	Sub Classes		
CLASS I	A - Nonperishable C - Combat Rations R - Refrigerated	S – Non refrigerated W -Water	
CLASS II	A - Air B - Ground Support Materiel E - General Supplies	F - Clothing G - Electronics M -Weapons	T - Industrial Supplies
CLASS III	A - POL for Aircraft W -POL for Surface Vehicles P - Packaged POL		
CLASS IV	A - Construction B - Barrier		
CLASS V	A - Air Delivery W -Ground		
CLASS VI	A - Personal Demand Items M - Personal and Official Mail P - Ration Supplemental Sundry Pack		
CLASS VII	A - Air B - Ground Support Materiel D - Admin. Vehicles	J - Tanks, Racks, Adapters & Pylons L - Missiles M -Weapons	N - Special Weapons T - Industrial Material X - Aircraft Engines
CLASS VIII	A - Medical Materiel B - Blood/Fluids		
CLASS IX CLASS X	A - Air B - Ground Support Materiel D - Admin. Vehicles G - Electronics	K - Tactical Vehicles L - Missiles M -Weapons N - Special Weapons T - Industrial Material	

Figure.4: Class and sub classes of military supply chain

In supply chain management, the flow carries in two ways i.e. downstream and upstream from factory to the end user. The end user may commercial customer or military user or any other depends on sector. In military, at initial point, the product will examine to determine accuracy, quality and condition. Hence, the products examination induces less status for reverse logistics. The baseline of military Supply Chain throughput was unavailable to secondary markets for military unique products like weapons, ammunition etc. In military, funding, purchasing actions, and technology changes are not reliable, since the risk is too high for industry to pre-position the components for the military.

In almost all supply chain networks, the raw material suppliers are at one end of the supply chain. In commercial, suppliers are connecting to manufacturers and distributors, which are in turn connecting to a retailer and the end customer. In general, the number of organizations begins with suppliers, who provide raw materials to manufacturers, which manufacture products and keep those manufactured goods in the warehouses. Then they send them to whole sales or distribution centers that ship the goods to retailers. The customers then buy products from retailers [10].

The sectors have slight differences concerning the structures of the supply chain networks. The figure.5 illustrates the scenario between commercial and military supply chains. In both supply chains consists of material and information flow.

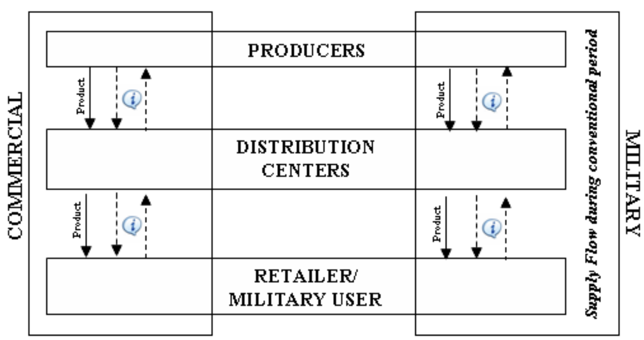

Figure.5: Three-Level supply chain networks

In commercial supply chain, retailer identifies the demand; communicate the demand information to distributor. When distributor receives the order information from retailer, checks the inventory level. If finds low, send the order information to producer otherwise accomplish the retailer request by supplying the product with prior information. If distributor finds low inventory then producer receives demand information from distributor to produces the products. As per distributor demand producer produces the product and sends the product to distributor with prior supply information. The above process exercised between three troops such as producer, distributor and retailer in commercial supply chain [10].

In military, as well, supply chain network can considered as three levels between producer, distributor and military user. The significant changes between military and commercial supply chain is product flow. In military, material flow can be view in two scenarios. One is conventional flow, which processed between producer, distribution centers and military user. The other one is nuclear flow, which comes at warfare. Where as the customer in military, may vary as Army, Marines, Air Force and Navy. In addition, figure.5 also presents military supply flow, which states the same scenario of commercial supply network. The military user identifies the demand and communicates the demand information to distribution centers. When receives the order information from military user, checks the inventory level at depots. From figure 4, it supposes that the material flows in military are in many forms. Existences of different material are stored at different depots thru distribution centers. If the depot find low inventory, send the order information to distribution centers otherwise accomplish the distribution centers request by supplying the product with prior information to distribution centers. In other case, a distribution center finds information about low inventory then sends demand information to producer, to produces the required products. With prior information producer produces and send product to distribution centers with supply information. Now distribution center directs the supplied product with supply information to distribution centre. The above process exercised between three troops such as producer, distribution centers and military user during conventional period [9]. Whenever the military posited in warfare, supply chain needs to transfers the information and material flow. Since the warfare is an emergency state of affairs which needed to support the operations with an essential materials such as arms and ammunitions. If the supply lines are, too long i.e. three level supply chain flows, it is extremely difficult to meet the military operations.

In Section III will briefly describe present scenario of military supply chain and their deficiencies. Moreover, describes the uncertainties in military supply chain. We consider the Lorenz system model to describe new model during warfare in Section IV. Finally presents the brief conclusions.

III. MILITARY SUPPLY CHAIN NETWORKS

A. Pressent scenario of military supply chain

During the First World War, military supply chains were managed as groups. Individual groups run their own processes for placing orders, maintaining and moving inventory to war fighters. With rapid changes in the global military operations, supply chain networks are coupled with all military groups/ hierarchical levels. In Military, war operations are rare events. During peacetime, as well, the military consumes resources that are similar to a commercial supply chain. However, military supply chain decisions heavily depend on strategy, tactics and intelligence than cost efficiency. During wartime, the supply chain decisions are depend on operational and tactical. The ancient warfare conducted by using conventional military weapons and battlefield tactics between two or more states with an open challenge. The idea behind the conventional warfare is to weaken or destroy the opponent's military force. With this conventional warfare, the supply chain and logistics issues can handle according to scenario. However, many changes influence the present military systems. The present situations were unable to predict the wartime and conduct the warfare without conforming to legality, moral law, or social convention. As each individual nation perceiving their welfare and getting more influence by political bodies. To support this enhanced speed, creating new challenges for military supply chain. However, the present military supply chain is becoming dynamic and getting more influence by political individuals.

The idea behind the present military supply chain upholders is to support their transformed combat force with fast, accurate and flexible supply line. To meet these challenges introduced many practical application of science and models. Also employs technologies, information systems and procedures to predict and prioritize military requirements and allowing for appropriate sustainment. Military supply chain models allowed the nation to new challenges for conducting surge operations. Combining the military and commercial strengths for better turnout and attaining optimal procurement, supply, maintenance and distribution times for efficient supply chain system. Real-time stock age information, just-in-time deliveries are also promoting by military sections [5]. In fact, military achieved possibility of future success, still receiving state of problems that needs to be resolve. From these problems military supply line is getting trouble. The problems makes ineffective to inventory management, waste, inefficiency, and delay across the supply chain. Military planners are attempting a set of scenarios and various probabilities to resolve problems.

B. *Uncertainites in Military Supply Chain Networks*

Even though in military, supply chain brings different uncertain demands to supply line. Because demand may occur with in short time and unpredictable. In military, the need may arise from basic supplies needs to with major items such as tanks, weapons. According to priority, indicated the supply line condition and made decision by hierarchic officials. The idea behind the military inventory is to ensure the stock on hand when required at warfare.

The above statements suppose that to anticipate or forecast the wartime. In urgency, military place an order and wait for the stock. Some time stock may get delay. In that situation military needs to accept the unnecessary prices even if stock gets too late or earlier. The situation may sort out as inventory holding costs for storage of stock or the cost for out dated items such as perishable. So here in military supply chain, the major identified problem as inventory visibility. Without stock visibility retailers as well as customers (i.e. military) struggles to commit an orders. The lack of visibility on inventory, results in miscalculated order quantities. In addition, peak time orders based on pinch demand causes shipping delays. Due to this poor visibility, military planners were unable to order in urgency. Therefore, inventory gets into trouble with this invalid prioritize. To accurate, the inventory level throughout the military supply chain needs to improve visibility and reduce transit delays [5].

The attention of a military supply chain is entirely different from that of a commercial supply chain. The military operates on an operational base, where the required commodities have to be transport to a soldier at the war front. The unique characteristic of military supply chain is its back-pipeline, which moves the 'goods' like injured troops and damaged equipment, in the reverse direction i.e. from the front line to its operational base . The military has tried to adopt many models practices from the commercial supply chains. However, the present military supply line head-on with demand. The head-on problem is that uncertainty demand occurrence with in short time. This uncertainty was unable to be identified in advance. From section II, the last statements state the military inventory maintenance. In inventory maintenance, activities are getting trouble in about events that keeps the stock on hand before the warfare. Inaccurate inventory forecasts can affect at a variety of process areas includes supply management, transportation, distribution depots, and depot maintenance. This in turn will have an impact on the cost of commodities, also a conflict occurs, increasing demand for supplies, and existing stock of material are insufficient. Accurate inventories are critical to maintaining readiness in the presence of variable demand.

IV. SYSTEM MODEL

The modeling process in this section exploits the results in Ref. [8]. Indeed this reference discusses some scenarios related to the flow of materials along a three-echelon commercial supply chain and models them by three coupled equations.

In this paper, we consider the case of a three-echelon military supply chain and explain some specific scenarios related to the flow of materials (i.e. arms and ammunitions). This interesting consideration can lead to various possible cases when dealing with the flow of materials from supplier to military user. Two striking cases can be envisaged. The first case (which is an ideal case) supposes the traffic of materials (with no inconvenience) along the three echelons of the supply chain and a good communication or exchanges between them as well. This case does not however describe a realistic scenario since an emergency (see second case below) can occur due to the malfunctioning of a significant number of arms or lack of ammunitions during warfare [11,12]. This situation is discussed later.

The modeling process of the first case is based on a comparative analysis between commercial and military supply chains in order to show that this specific scenario can be modeled by the set of the equations in Ref. [8].

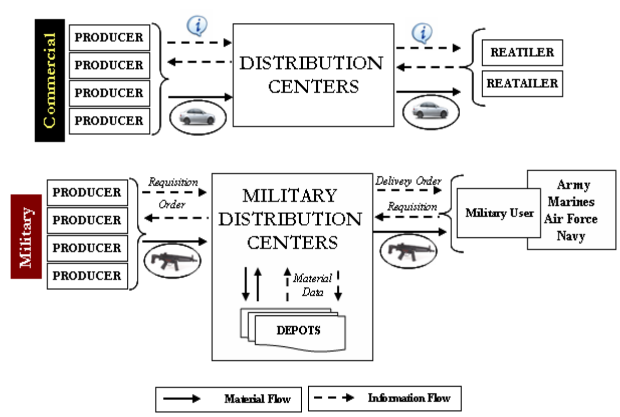

Figure.6: In First case the Material and Product flows in Military and Commercial supply chains

In figure.6, the demand information is transmitting with in the layers of the military supply chain with a delay of one unit time. This indicates the information flow from military user to producer and vice versa. In addition, the materials flow from the producer to military user via distribution center. As illustrated in figure.6, three-layer military supply chain model can show in mathematical expression as equations. The equations are derived from the Ref. [8].

The quantity demanded by military user for material in current period is decides that how much of demand is satisfied in previous period. The demand can obtain from previous inventory level at distributor, delivery efficiency of distributor and the user (i.e. military) demand satisfaction. This can be represented as shown in equation (1)

$$x_i = my_{i-1} - nx_{i-1} \ldots\ldots\ldots\ldots\ldots\ (1)$$

At distributor level, needs to take the combined effect of military user and producer into consideration before making an order. In distributor center, makes their decision on inventory levels Apart from this distributor, also need to take into consideration the expected loss rate that can take place on the producer's supplies. This can be represented as shown in equation (2)

$$y_i = rx_{i-1} - x_{i-1}z_{i-1} \ldots\ldots\ldots\ldots\ (2)$$

The producer's production typically depends on the distributor's orders and the safety stock. However, distributor's orders are again depended on military user order, i.e., the producer needs to take the combined effect of military user and distribution into account before making production at producer position. This can be represented as shown in equation (3)

$$z_i = x_{i-1}y_{i-1} + kz_{i-1} \ldots\ldots\ldots\ldots\ (3)$$

Notations:	i	*Time period*
	m	*Distributors efficiency while delivering the product*
	n	*Ratio of customer demand satisfaction*
	r	*Distortion coefficient*
	k	*Safety stock coefficient*
	x_i	*The quantity demanded for products*
	y_i	*Inventory level of distributor*
	z_i	*The quantity produced by producer*

Where

- $x_i < 0$ denotes that the supply is less than military demand in the previous period.
- $y_i < 0$ denotes that critical information without adjustment is necessary to inventory level.
- $z_i < 0$ denotes the cases of overstock or return and no new productions [8].

The three differences equations are quantity demanded by military user, inventory level or quantity demanded by distributors and quantity produced by producers. The above equations and statements are considered as first case. The three-echelon military supply chain model is accepted from a well-known model i.e. Lorenz model and described in Ref. [8].

However, in military the major concern and purpose of optimizing the supply chain is warfare. During these situations, the military user communicates demand and expects the material supply with an immediate affect. In these situations, if supply lines are too long then it is extremely difficult to support the warfare operations. To reduce the time delay and to improve the supply flow from producer to the military user need to introduce a novel scenario. The new proposed model needs immediate deliver or transmission of material to the military user at war locations. However, the first case does not supply the material with an immediate affect during warfare.

The second case seems to be more interesting as it could describe a realistic scenario (an emergency case) which can occur due to the malfunctioning of a significant number of arms or lack of ammunitions during warfare [11,12]. This is a specific case where a stretch forward action is needed to provide arms and ammunitions to military user. To satisfy the demand, a direct flow of material from supplier to military user is justified since the material flow thru distributor will be not only time consuming but also not appropriate as a situation can occur at the level of distributors (accident, some problems during transportation etc.). Therefore, this second case is an emergency scenario, which will be combines to the first case in order to describe a more realistic scenario.

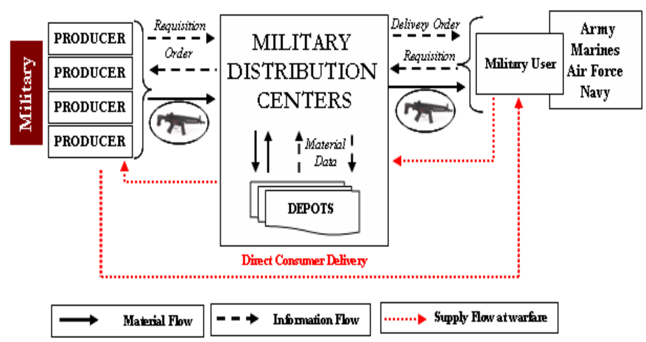

Figure.7: In second case (during emergency), the material flows in military supply chains

In military, war is an essential consequence, must be ready to move to the conflict location and need to carry the sufficient material. If the military users waiting time increases or delays then the flow of supply products are delayed, this gives unmanageable impression to entire military operations. The consideration of second case intends to deliver or transmission of material to the military user at war locations. While considering the second case, initially necessary to conceive the key points such as quantity produced, safety stock coefficient during emergency.

Considering such a scenario, the supplier unit suppliers in both directions (z_i: in the former direction in the directions through distributor) and (w_i in a straightforward (direct) way (i.e. directly to military user)).

Therefore:

Additional Notations:	w_i	*quantity produced by producer (due to emergency)*
	l	*loose in safety stock coefficient (due to emergency)*
	$(k-l)$	*current safety stock coefficient*

Under these considerations, equation (3) is modified as follows:

$$z_i = x_{i-1}y_{i-1} + (k-l)z_{i-1} \ \ldots\ldots \ (3')$$

Where by this new form of equation (3) takes into account the current safety stock.

Further, the flow in the direction due to emergency is expressed as follows:

$$w_i = kz_{i-1} - lw_{i-1} \ \ldots\ldots\ldots\ldots\ldots \ (4)$$

Where kz_{i-1} is the previous stock and lw_{i-1} is the quantity subtracted on the previous stock due to emergency case.

There the following complete equations describe the scenarios envisaged in the second case:

$$x_i = my_{i-1} - nx_{i-1} \ \ldots\ldots\ldots\ldots\ldots \ (1)$$

$$y_i = rx_{i-1} - x_{i-1}z_{i-1} \ \ldots\ldots\ldots\ldots\ldots \ (2)$$

$$z_i = x_{i-1}z_{i-1} - (k-l)z_{i-1} \ \ldots\ldots\ldots \ (3')$$

$$w_i = kz_{i-1} - lw_{i-1} \ \ldots\ldots\ldots\ldots\ldots\ldots \ (4)$$

CONCLUSION

This paper was concerned with the modeling of material flow (arms and ammunitions) along a military supply chain. The structure of the proposed military supply chain is made up of a three-echelon. The first part of this work has dealt which a general overview which aimed to position the work and to explain current scenario encountered in military supply chain. The model process was inspired on that carried out in reference [8]. The first case showed a scenario along military supply chain which is comparable to that exhibited in a three-echelon commercial supply chain. A comparative analysis aimed to show that this case could be modeled by the equations in reference [8]. However, the scenario in the first case has been shown not to be more realistic. Indeed many references (see references [11,12]) have shown an interesting scenario which currently occur in a military supply chain in addition to the scenario discussed in the first case. This interesting scenario in addition to the scenario case one could described a realistic scenario (an emergency case) which can occur due to the malfunctioning of a significant number of arms or lack of ammunitions during warfare [11][12] This paper has discussed such a scenario and appropriate model (i.e. set of equations) was proposed to model this scenario.

The work in this paper is the first step towards complete modeling of the realistic scenario encountered in military supply chain. Therefore, it will of high interest the use of the proposed model to analyze various scenario that can be exhibited along military supply chain. This is an interesting issue as the results from the modeling process may be compared to the real scenario encountered in military supply chain in order to validate the proposed model.

REFERENCES

[1] Antill, P. *Military Logistics: A Brief History*, by Military History Encyclopedia on the Web, 22 August 2001.

[2] Steve John Simon, The art of military logistics, by Association for computing machinery, Volume 44, No.6, June 2001.

[3] Eric Peltz, “Logistics: supply based or Distribution based ?”, by RAND Arroyo center, Volume 39, Issue 2 PB 700-08-02, 2007.

[4] Major Joshua M.Lenzini, “ Anticipatory Logistics: The army’s Answer to supply chain management”, by Army Logisitician, issue 2002, PB 700-02-5.

[5] F.Barahone, P.Chowdhary, M.Ettl, P.Huang, T.Kimbrel, L.Landanyi, Y.M.Lee,B.Schieber, K.Souriranjan, M.I.Sviridenko, G.M.Swirszcz, “Inventory allocation and transportation scheduling for logistics of network-centric military operations” by IBM J.RES. & DEV., volume.51 No. 3/4, 2007.

[6] Wang Jinfa, Li Li, Military Supply Chain Management - the Science and Art Supporting Military Operation, Beuing: National Defense University Press, 2004.

[7] DoD Logistics, Chapter 4, Joint Publication 4-09 “Joint Doctrine For Global Distribution” issu-e JP 4-09, 14 December 2001.

[8] Z.Lei, L.Yi-jun, and X.Yaoqun, “Chaos Synchornization of bullwhip Effect in a Supply Chain,” presented at Management Science and Engineering, 2006. ICMSE’06. 2006 Internationl conference on, Lille, Date: 5 – 7 Oct. 2006.

[9] Mark Y.D.Wang, “Factory to Foxhole:Improving the Army’s supply chain”, presented by RAND Corporation, September’2006.

[10] David F. Pyke and M. Eric Johnson (editors), “Supply Chain Management: Innovations for Education”, by Production and Operations Management Society, POMS Series in Technology and Operations Management Volume 2, , 2000

[11] Daniel W.Engels, Robin Koh, Elaine Lai, Edmund W.Schuster, “An introductory analysis of Auto-ID applications in the department of defense supply chains”, by Auto ID Center, 2002

[12] Michael Brzoska, Frederic S, “Arms and Warfare: Escalation, De-escalation, and Negotiation”, Book, Published 2006 DIANE Publishing Company, ISBN:142235296X

Sreeram Kumar Bhagavatula received his BSc in Computer Science and MSc in Computer Science from Andhra University, India, in 2001 and 2003, respectively. He worked as project operations in Indian railways from 2004 – 2007. He is now a Ph.D. student at the University of Klagenfurt in Austria. His research interests include military supply chains, city logistics, multi-agent systems, chaos and its applications.

Jean Chamberlain Chedjou received in 2004 his doctorate in Electrical Engineering at the Leibniz University of Hanover, Germany. He has been a DAAD (Germany) scholar and an AUF research Fellow (Postdoc.). From 2000 to date, he has been a Junior Associate researcher in the Condensed Matter section of the ICTP (Abdus Salam International Centre for Theoretical Physics) Trieste, Italy. Currently, he is a senior researcher at the Institute for Smart Systems Technologies of the Alpen-Adria University of Klagenfurt in Austria. His research interests include Electronics Circuits Engineering, Chaos Theory, Analog Systems Simulation, Cellular Neural Networks, Nonlinear Dynamics, Synchronization and related Applications in Engineering. He has authored and co-authored 2 books and more than 22 journals and conference papers.

Koteswara Rao Anne received his BE in Electronics and Communication and MSc in Electrical engineering and Information Technology from Bharathiyar University, Coimbatore, India and Leibniz University of Hanover, Germany, in 2001 and 2006, respectively. He is now a Ph.D. student at the University of Klagenfurt in Austria. His research interests include advanced planning and scheduling in production systems, Intelligent supply chains, systems dynamics, multi-agent systems, chaos and its applications.

Kyandoghere Kyamakya obtained the M.S. in Electrical Engineering in 1990 at the University of Kinshasa. In 1999, he received his Doctorate in Electrical Engineering at the University of Hagen in Germany. He then worked three years as post-doctorate researcher at the Leibniz University of Hannover in the field of Mobility Management in Wireless Networks. From 2002 to 2005, he was junior professor for Positioning Location Based Services at Leibniz University of Hannover. Since 2005, he is full Professor for Transportation Informatics and Director of the Institute for Smart Systems Technologies at the University of Klagenfurt in Austria.