Visualizing the Logistics Dimension with Map-Based Simulations

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ABSTRACT

Designers of tactical and skills training simulations are understandably reluctant to slow the pace of user interactions in those simulations with complicated rules and calculations to address logistics that support the activities occurring in those simulations. Tactical and training simulations therefore handle logistics only in the abstract. Yet, after the skill and bravery of the troops, logistics is perhaps the next most critical factor in the success of any mission.

This paper shows how an accurate logistics dimension can be added to any tactical or skills training simulation or federation of simulations. A map-based supply chain modeling and simulation application can connect to a federation of other training simulations in a unified training scenario. This enables people to see, understand and manage the supply chains required to support operations happening in other training simulations. (Aldrich, C. 2004) It adds a new layer of reality to other simulations, and enables realistic training of logistics personnel in a way not previously possible.

In 2019 we successfully completed a subcontract on a DoD proof of concept project demonstrating how to model and simulate supply chains to support events occurring in a federation of simulations comprising a unified training scenario. Based on that work, we present a conceptual design for the user interface (UI) which makes the simulations easy to understand and use by a wide range of people. And we present the technical architecture used to connect the supply chain simulation to a federation of other training simulations. Additionally, we show how this builds on a project done with the Global Logistics Cluster of the World Food Program in 2016 to create an online logistics training platform for use by its staff and staff of other humanitarian organizations.

ABOUT THE AUTHORS

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INTRODUCTION

Traditionally the Interservice, Industry Training Simulation and Education Conference (I/ITSEC) has displayed training simulators portraying a wide range of specific training devices such as sonar trainers, driver trainers, maintenance trainers, medical trainers, etc. The conference rarely includes simulations for logistics strategy or tactical training because logistics is conceptual, and does not provide the dynamic excitement offered by virtual-reality or augmented-reality training devices. In this paper we illustrate how visually engaging and easily understandable supply chain simulations can be used to improve logistics training. The paper starts with a short statement of the need for and challenge of creating an easy to use logistics training simulation. Next is an overview of the simulation logic and the accompanying user interface for setting up and running the simulations. Lastly, a low overhead academic option is presented for using simulations in a classroom setting or a distributed learning setting.

The coronavirus pandemic (COVID-19) illustrated the importance of supply chains throughout the world. Supply chains once taken for granted were suddenly viewed from a different perspective. The importance of managing risk with backup supply chains and multiple sources of supply was realized. The impact of the virus pointed out the inefficiency of existing supply chains in the United States, and the lack of trained supply chain personnel to plan and manage them. This emphasized the need to provide more and better training in logistics and especially in supply chain management.

SUPPLY CHAIN AND LOGISTICS TRAINING SIMULATIONS – A CONCEPTUAL DESIGN

The number of universities offering majors in supply chain management is growing to meet increasing demand for supply chain professionals. Civilian and military educators are using state of the art technology to engage students who have grown up with computers and are not afraid of experimenting with new technology to discover information and develop new skills. However, computer based instruction is often at its best when used to deliver real-time, 3D or virtual reality (VR) visualizations in the form of highly accurate simulations. This is a powerful way of building skills because it engages our visual sense which is our highest bandwidth sense, and also because we are used to seeing the world in real-time 3D already, so we quickly understand simulations that use this visual approach.

However, it is a challenge to apply this approach to visualize supply chains. Virtual reality and 3D simulations work well for line of sight environments such as inside facilities or vehicles, or for outside environments that are within eyesight. Facilities and vehicles are all parts of a supply chain, but they are not in themselves a supply chain. Supply chains stretch across cities, regions and around the world. They are continually evolving systems that extend beyond the line of sight of any single person. This makes it impractical to use virtual reality displays as they are in other simulations. The challenge then is to find a way of visualizing the status and interactions between all the facilities and vehicles in a supply chain in a way that is as easily understood as VR displays.

Supply Chain Definition and Modeling Logic

A supply chain "… *consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves*." (Chopra, Meindl, 2015, Supply Chain Management: Strategy, Planning and Operations, 6th Edition, Upper Saddle River, NJ: Prentice-Hall, Inc. Chapter 1)

Based on this definition of a supply chain, one can create an accurate yet simple model of supply chain logistics with just four entity classes:

1. Products – things in demand (i.e. requested by customers) at various facilities
2. Facilities – places where products are made, stored, sold or consumed
3. Vehicles – mechanisms to move products between facilities to meet demand
4. Routes – paths taken by vehicles to move products between facilities

There is also a fifth entity built into this model. That entity is time. Facilities have attributes such as product demand and operating costs that are expressed as a rate over some period of time from minutes to days, weeks, or months. Vehicles have attributes such as speed and operating cost that are expressed as distance divided by time. And routes have travel times for the vehicles that travel them based on the length of the route and the speed of the vehicle.

Instances of these four entities can be created as needed to define the different products, facilities, vehicles and routes involved in any given supply chain. The individual instances of these four entity classes become the agents in an agent-based model that can accurately define operations in any supply chain anywhere in the world. And the model logic works at any scale from low-level, detailed models of local supply chains to high-level, aggregate models of regional and global supply chains.

The use of this supply chain model calls for a user interface (UI) design that enables people to easily define instances of the four entities in their supply chain models. That UI must also provide an organizing context that is as engaging and easy to understand as the VR interfaces used in other training simulations.

UI Conceptual Design

Simulations of supply chain networks traditionally rely on the use of abstract flow charts to model supply chains and require users to have advanced mathematics skills. They offer the user options to simulate and display results from applying various inventory, facility, and transportation formulas to a supply chain model. However, the user must have an understanding of what formulas to use as well to be able to interpret the results. This restricts use of such simulations to a relatively small group of logistics specialists.

This paper proposes a different approach – one that employs a visual UI based on the use of supply chain entity icons that are created and dragged and dropped on a smart map such as Google Maps. This enables quick creation of accurate supply chain models without needing to interact with abstract flow charts or advanced mathematics. (Hugos, M. 2018) This UI makes the application understandable and usable by a wide audience of operations, managerial, professional and academic people involved in logistics and supply chain management. (Wisner, Tan, Leong, 2016).

The use of a map-based UI with entity icons enables the addition of a logistics dimension to other training simulations because it presents supply chain modeling and simulation information in a quick and understandable visual format. The map-based UI provides an organizing context for displaying supply chain structures, operation data plus supply chain data generated by other simulations in a federation of simulations. Instances of these four entities are defined using a small dataset for each entity as shown in Figure 1 below. As these instances are defined, icons appear onscreen and users drag and drop the icons to place them on a smart map such as Google Maps.

Users can zoom in on the map and have the option of switching to satellite view to place existing facilities, vehicles and routes where they actually are located. Users can also place new facilities, vehicles and routes where they want them to be in order to expand and improve existing supply chains or create new supply chains (Watson, Lewis, Cacioppi, and Jayaraman, 2013); Manivannan, M.S, 1998) This generates the data needed to create a rigorous mathematical model of the supply chain. (Hugos, M. Online Guide: Getting Started, 2015)

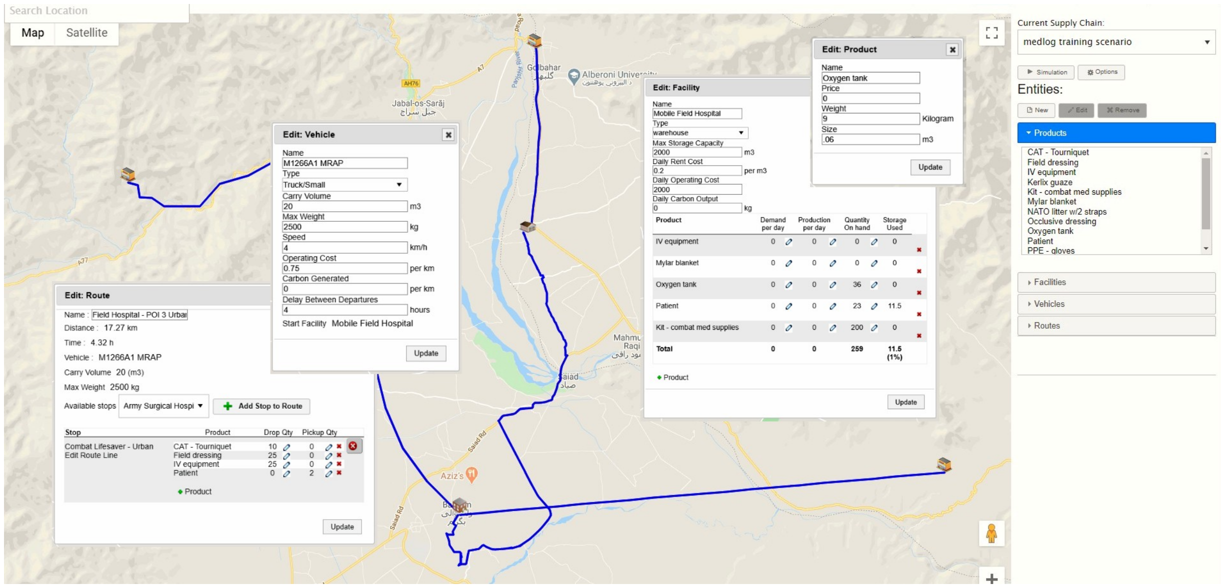

Figure 1. Instances and icons from the four entity classes: Product; Facility; Vehicle; and Route

The UI also makes use of heads-up displays (HUDs). As shown in Figure 1 above and Figure 2 below, detailed data about the supply chain model and the simulation results are shown in dialog boxes overlaid on maps and satellite photos and in sidebar displays on the right side of each screen. Seeing this detailed data within a larger map-based context, helps users gain situational awareness, and avoid getting lost in the details. All the data users need for editing a supply chain model is presented on a single screen for ease of use (Figure 1). And all simulation data is also presented on a single screen for ease of understanding (Figure 3).

This UI design minimizes the need to navigate through multiple screens while editing supply chain models and running simulations. The UI integrates HUD functionality and simulation capabilities, and leverages the capabilities of Google Maps to provide map and satellite views. The supply chain simulation software application could also leverage other smart maps containing the needed functionality such as Apple Maps, Bing Maps, or Open Street Maps. (Hugos, M. Online Guide: User Interface, 2015)

Simulation Logic Overview

Because each agent in this model has a time attribute built in, this agent-based model can be combined with a discrete event simulation (DES) approach (Dubiel, Benjamin & Tsimhoni, Omer. (2006). This enables simulations to show both the overall state of an entire supply chain network as well as the state of each individual entity within the supply chain in moment by moment increments as simulations play out over time.

The initial supply chain model defines a point of departure for the simulation. The simulation calculates the interactions between agents in the supply chain and updates and displays the relevant attributes for each agent at the end of each time interval. The time interval for simulations can be defined by the model to be minutes, days, or weeks.

Simulations display the results of interactions in a supply chain model between instances of the four entity classes. Simulations track the flow of products through a network of facilities (a supply chain), and calculate related operating costs and key performance indicators (KPI) over any number of hours, days or weeks (Hugos, M. Online Guide: Supply Chain Modeling and Simulation Logic, 2015)

The simulation engine uses DES with a deterministic, non-linear model (Allen, T.T., 2011; Persson, F. and Araldi, M., 2009). This causes the simulations to exhibit what is known as "deterministic chaos." This is because simulation results are highly sensitive to initial starting conditions as defined in each individual supply chain model. Small changes to a model can produce results that may appear counter-intuitive, unpredictable, or even chaotic.

There are endless changes and combinations of changes one can make to the different entities in a supply chain model. And each time a change is made, the simulation takes a unique trajectory determined by the cumulative effect of all the changes made up to that point (Cattani, Mauro, Caldas, Iberê Luiz, Souza, Silvio Luiz de, & Iarosz, Kelly Cristiane, 2017).

Simulations can be paused and re-started as needed to investigate specific developments in particular parts of a supply chain. Simulation data can be exported into a comma separated values (CSV) file and analyzed from various perspectives using different formulas such as Economic Ordering Quantity, Break Even Analysis, Cost Benefit Analysis, etc. (Thuesen, G.J. and Fabrycky, W.J. 2001; Chopra, S., and Meindl, P, 2013) The data can also be used to generate reports. A mission reporting template is provided to import simulation data and produce product usage and cost reports plus relevant key performance indicators (see Figure 6).

CONNECTING SUPPLY CHAIN SIMULATIONS TO A FEDERATION OF SIMULATIONS

Imagine a unified medical training scenario that took place in Afghanistan. One such scenario covered medical activities performed in a surgical hospital located at Bagram Airbase and medical activities performed at a mobile field hospital with several points of injury (POI) in the field. Also included were medical activities occurring in vehicles transporting wounded troops to treatment facilities.

A proof of concept training system called Point of Injury Training System (POINTS) was created to explore scenarios like this. Figure 2 below shows a collage from training simulations that covered different types of medical care delivered during a unified training scenario. A logistics dimension was added to this training scenario by linking the supply chain simulation to a federation of other simulations. (Duke, D. and Hugos, et al., 2019).

Figure 2. Different medical skills training simulations are combined in a unified training scenario

Shown above, top right and left, are two medical trainees in a field hospital working on a patient during a virtual reality simulation occurring at a POI in the scenario. As they work, they use products in their simulations to carry out various activities. This product usage is recorded and shared with the supply chain simulation software program.

Bottom left shows a patient being evacuated from POI to Bagram surgical hospital. Care given in an operating room at the surgical hospital is shown in the screenshot lower right. These simulations are independent simulations running in the federation of simulations for this training scenario. Medical caregivers work with their simulations as part of their own virtual reality medical training program. When supplies are used by medical providers it depletes the supply of those products at the facility or vehicle. The supply chain simulation software keeps track of this and shows the logisticians how much inventory remains in any specific stocking location.

The Supply Chain Model Shows where Other Simulations in the Training Scenario are Happening

In this scenario Bagram Airbase was designated as the operations and logistics hub that supported medical activities in surrounding locations which were part of the scenario. From the scenario description a supply chain model was created. That model was a combination of instances of the four supply chain entities: products; facilities; vehicles; and routes.

Facilities and vehicles in the supply chain represented other simulations in the federation of simulations that made up this unified training scenario. Facilities were located on the map in the real locations where different medical activities were actually taking place. The user could zoom in on the map and turn on the satellite view to locate those facilities and vehicle routes. The user had the option of leaving them where they actually were located in the real world, or placing them in a new more optimal location thus creating a new supply chain.

The screenshot in Figure 3 shows an example of this. There are three facilities showing location of the POIs, and there are facilities positioned where the field hospital and surgical hospital are located. Vehicles from helicopters to armored personnel carriers are defined, and the routes they traveled to move products and patients between facilities are shown.

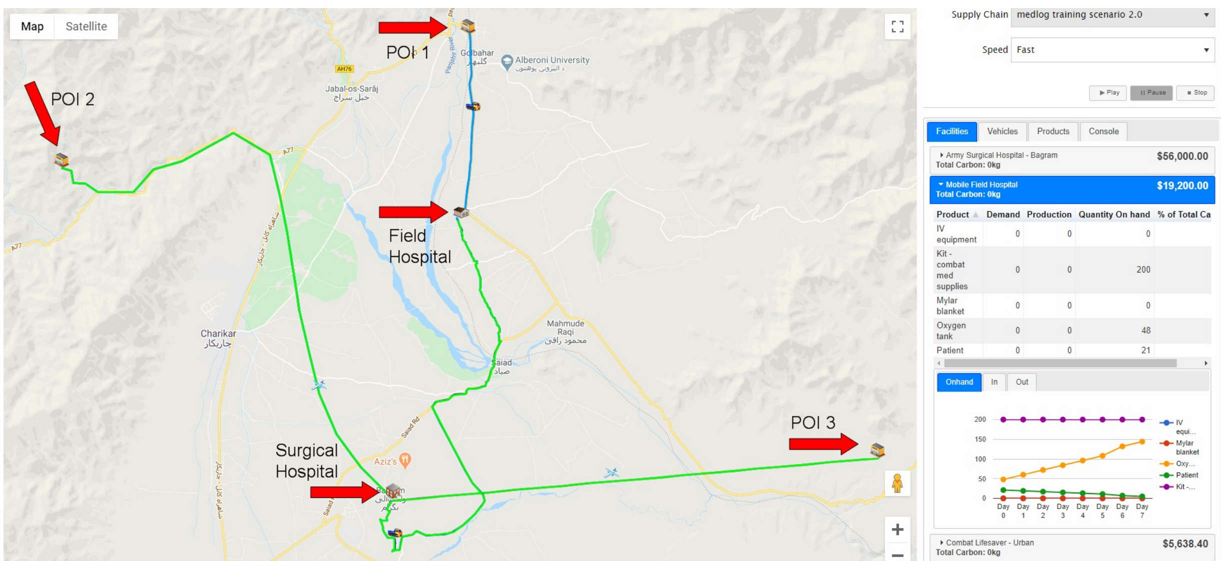

Figure 3. Facilities, vehicles, and routes are located on a map and simulations show operating results

At the start of a training scenario, each of the facilities and vehicles (representing the other simulations in the federation) had a set amount of products on-hand (i.e., medical equipment, bandages, medicine, etc.). Medical logistics personnel then designed a supply chain to deliver products to meet forecasted demands in the facilities and vehicles as the scenario played out. As activities occurred in each individual simulation, their product usage and product on-hand status were communicated to the database in the supply chain simulation software where it was displayed in real-time as shown in the screenshot above.

To do this they had to create a supply plan that met projected demands during the length of time covered by the unified training scenario. This means logistics planners had to define the vehicles and delivery routes they would use to support operations in the scenario. Those vehicles were assigned to the facilities where they were based. For each vehicle one or more delivery routes were identified along with product delivery frequencies and amounts to support operations at each facility. Vehicles were also assigned to move patients from the POIs to appropriate care facilities.

Technical Architecture Conceptual Design

The supply chain simulation connects with the federation of training simulations using a run-time interface (RTI) and high-level architecture (HLA) module developed specifically for the task of enabling different simulations to exchange data and commands. (Pitch Technology, 2019) This is illustrated in Figure 4 below.

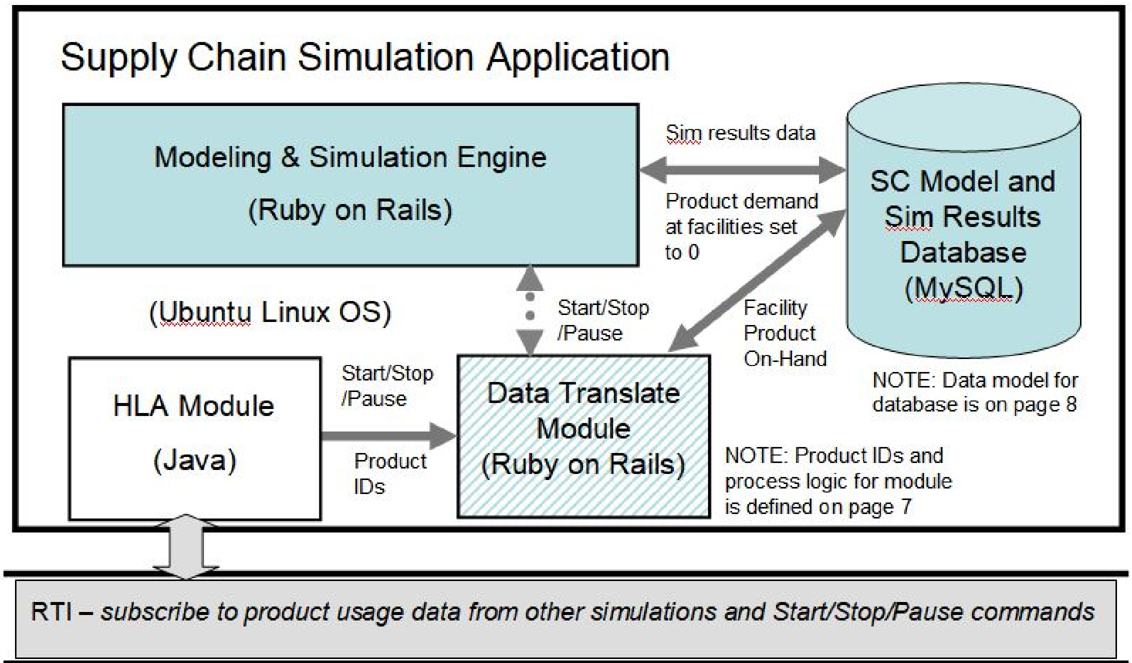

Figure 4. Conceptual Design for Connection with Federation of Simulations

The supply chain modeling and simulation software is written in Ruby on Rails (RoR), and uses the MySQL database. It runs on a server under the Ubuntu Linux operating system. This programming language, database and operating system were selected because they are popular products with a wide audience of application developers who are skilled in their use.

Processing Logic for Data Transfer Module (DTM)

To facilitate the connection with the RTI, a DTM was created to interface with the HLA module. The DTM responded to the Product ID and usage data sent by the HLA Module and updated the supply chain simulation database with relevant product information from other simulations in the federation as shown in Figure 5. It also alerted other simulations in the federation when the on-hand amount of any of their products reached zero items or less. This logic is outlined in Table 1 below:

Product and Usage Monitoring For each Product ID and usage amount read stored amount in database for that product at facility where use occurs deduct usage amount from on-hand product amount at that facility update on-hand amount in the database with new number For each Product ID and on-hand amount read on-hand amount in database for that product at each facility if on-hand amount is zero or less than zero send out-of-stock alert for that Product ID and pause affected simulation	(1)

Table 1 Product and Usage Module

A challenging technical aspect of integrating this supply chain simulation with real-time 3D training simulations was the different ways data is typically handled in VR training simulations and in the supply chain simulations. This supply chain simulation software uses a business information processing approach for handling and storing data. It uses a relational database as the central data store. Model and simulation data is stored on disk not in memory. In real-time 3D training simulations data for product usage numbers are stored as objects in memory. A data translation module (DTM) had to be created to handle the need to move data between in-memory objects and on-disk records.

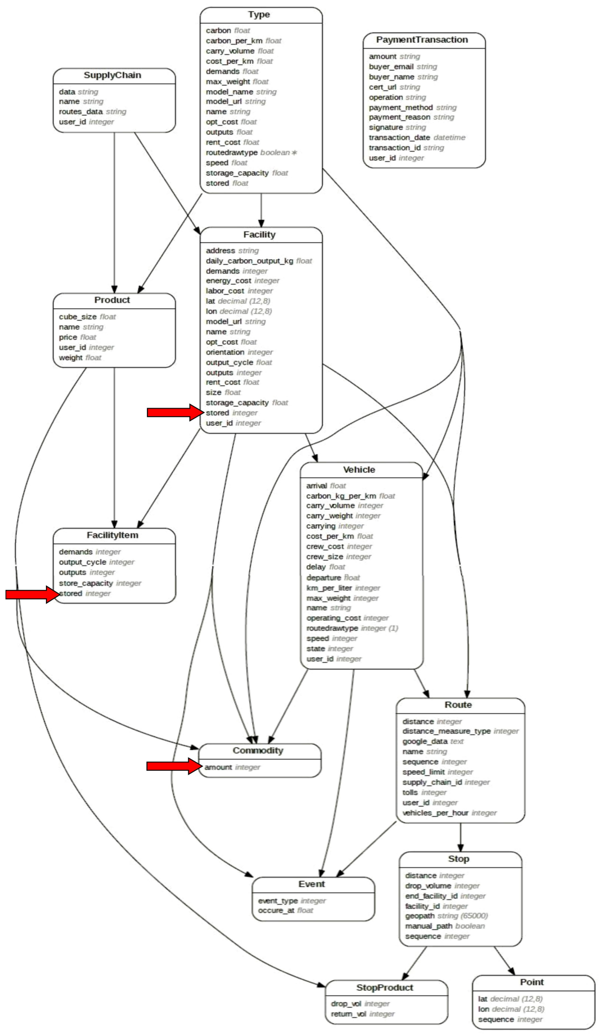

Figure 5. Data Model for Simulation Database

When facility and vehicle entities are defined by logistics planners this loads the simulation database with starting data for products on-hand at facilities and vehicles in the supply chain. Those starting numbers are communicated to other simulations in the unified training scenario.

The DTM updates product on-hand quantities at facilities based on product IDs received from the HLA Module. Assume one product is used each time a product ID is received from a facility or vehicle. Red arrows in Figure 5 show the data updated in the supply chain modeling and simulation database by the DTM. Updates are based on real-time input from the HLA Module as a training scenario runs.

The DTM sends an alert to the HLA Module if on-hand amounts of any Product ID at any facility or vehicle is zero or less. Start/Stop/Pause functionality is used to pause the affected simulation(s) in the federation of simulations.

Logistics personnel confer in real-time during the training scenario with technical specialists in the affected simulation(s) to better understand product demand. They update product delivery amounts and frequencies on the supply chain routes supporting that simulation.

The time scale of the supply chain simulation is synchronized with the real-time pace of the other training simulations. Although the normal time clock for supply chain simulations is hourly, vehicle speeds and facility demand/production rates are adjusted to change the simulation time clock to tenths of hours. Simulation results are displayed at smaller intervals measured in minutes, not hours or days.

Product demand at facilities in the supply chain model was initially set to zero (0) and demand was recorded from product usage data received from other simulations. However any amount of product demand can be used based upon the specific intentions of the simulated scenario. Updates to product on-hand amounts in the database came from two sources: 1) The HLA - DTM connection; and 2) deliveries that occurred in the supply chain simulation as defined by routes in the supply chain model. Updates to on-hand amounts for products at facilities in the federation of simulations are shown in existing data displays on the “Simulate” screen as the simulation runs. This is shown in Figure 3.

A LOW OVERHEAD SUPPLY CHAIN TRAINING OPTION

There is also a simple, low overhead option that uses the supply chain simulations to provide training in a classroom setting or distance learning setting. Simulations show how standard formulas (formulas for facility utilization and location, transportation, inventory, etc.) affect the results of supply chain operations. Students learn when to apply equations and when to apply their own insights to resolve problems found in the simulations (Duke, 2014-2020, Florida Institute of Technology). This low overhead academic option has been used over the last six years by community colleges, universities and graduate schools worldwide (Hugos, 2014-2020, SCM Globe Corp.).

In addition, the simulations have been used by humanitarian organizations. They can be used as an online logistics training platform for individuals who are employed in logistics support for humanitarian and disaster response operations. Supply chain models can be built and simulated to support planning for real supply chains to be deployed for a humanitarian mission. Simulation can also be used during an actual disaster to make on-the-spot decisions regarding how best to respond to expected and unexpected developments. (Duke, D and Hugos, M. 2016)

Lastly, the simulations can serve as a training tool for military logisticians. As a well-known saying states, "Amateurs talk strategy; professionals talk logistics." The supply chain simulations described in this paper are a modern-day replacement for the old terrain tables used in wargaming also providing more functionality and ease of use. (Hugos M, Sabin P, 2017). The simulations can handle all 10 categories of military supply so logisticians can consider all supply needs in their design of supply chains to support specific missions. Logistics planners create supply chain models and simulations give them immediate feedback on performance of their models. They continue to improve their models based on feedback until they get desired performance levels. The models then become the operating plans to deploy and operate real supply chains. (Duke D, Hugos M, Morrissey W, 2016).

Simulation data generated by academic, humanitarian or military users can be downloaded and imported into a mission reporting template shown in Figure 6 below. The reporting template has an operations report and a performance dashboard for analyzing simulation data. This reporting template is built for a 15-day period and can be extended for further days as needed. The operations report shows facility and product detail, and the dashboard shows where the best opportunities are for improvement

	A	B	C	D	E	F	G
1	MISSION OPERATING COSTS AND SUPPLY CHAIN PERFORMANCE - Nepal Earthquake 2015						
2							
3		**Total In-Country**	**Kathmandu DC**	**Dhading Whse**	**Barbare Whse**	**Charikot Whse**	**Deurali Whse**
4	**OPERATING COSTS**						
5	Cost of Products Used	$11,514,225	$0	$2,624,475	$2,198,250	$3,946,875	$2,744,625
6	Facility Storage and Ops Cost	870,000	210,000	165,000	165,000	165,000	165,000
7	Transportation Cost	51,002,848	23,423,848	8,994,600	18,179,200	210,000	195,200
8	Cost of Products Delivered	23,659,505	11,787,950	4,097,955	1,308,300	3,957,050	2,508,250
9	Transport Pct of Prod Delivered	216%	199%	219%	1390%	5%	8%
10	**Total Expenses**	$63,387,073	$23,633,848	$11,784,075	$20,542,450	$4,321,875	$3,104,825
11							
12	**INVENTORY UTILIZATION**						
13	Beginning Inventory Value	$10,448,790	$3,859,105	$1,716,585	$1,685,950	$1,306,125	$1,881,025
14	Ending Inventory Value	$11,103,965	$3,911,950	$3,190,065	$1,041,000	$1,316,300	$1,644,650
15	Percent Change	6.27%	1.37%	85.84%	-38.25%	0.78%	-12.57%
16							
17	**STORAGE UTILIZATION**						
18	**Facility Storage Capacity (m3)	50,000	10,000	10,000	10,000	10,000	10,000
19	Average Inventory Volume (m3)	18,691	7,163	4,382	2,099	2,068	2,980
20	Percent Utilization	37%	72%	44%	21%	21%	30%
21							
22	SUPPLY DEPOT PERFORMANCE						
23							
24		**Total Depots**	**Kolkata**	**Brindisi**	**Kuala Lumpur**	**Shanghai**	
25	**OPERATING COSTS**						
26	Cost of Products Shipped	$13,879,475	$4,013,900	$2,892,500	$4,444,075	$2,529,000	
27	Transportation Cost	23,423,848	870,480	8,080,000	8,633,368	5,840,000	
28	Transport Pct of Prod Shipped	169%	22%	279%	194%	231%	
29	**Total Expenses**	$37,303,323	$4,884,380	$10,972,500	$13,077,443	$8,369,000	
30							
31	**Note - asterisks require user data entry						
32	All other data is from simulation results						
33							

Figure 6. Mission reporting template shows operating costs and utilization of products, facilities and vehicles

CONCLUSION AND LESSONS LEARNED

The supply chain modeling logic based on the four entities (products, facilities, vehicles, routes) and the accompanying UI employing a map-based design provides a quickly understood organizing context that makes the supply chain simulations usable by a wide operational, managerial, and academic audience. Instances of the four entities created and positioned by dragging and dropping on a smart map creates a rigorous mathematical model of any supply chain without requiring the user to interact with abstract flow charts or deal with advanced mathematics.

The proof of concept project demonstrated how these supply chain simulations can be used to add an accurate and easy to understand logistics dimension to a federation of other VR training simulations. Work with academic and humanitarian organizations demonstrated the effectiveness of the simulations as learning tools to teach principles and practices of logistics and supply chain management. The simulations have been shown to be effective in both classroom and distance learning settings.

An important discovery is that map-based supply chain simulations also provide an effective context for logistics personnel to participate simultaneously in joint online training exercises. Supply chain models can be rapidly defined and simulated in collaborative online exercises with other people from different organizations in different parts of the world. Additionally, the situational awareness generated by this exercise facilitates group consensus and enhanced decision making.

The simulations provide a simple and straightforward way to explore the operations and examine the financial performance of different supply chain designs. And results show that performance reports produced by simulation data provide an objective basis for analysis and for comparing the merits of different supply chain designs.

KEYWORDS

- AGENT-BASED SIMULATION
- COLLABORATIVE
- DISTANCE LEARNING
- LOGISTICS TRAINING
- RAPID MODELING

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