A Game-based Approach towards Facilitating Decision Making for Perishable Products: An Example of Blood Supply Chain

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Abstract: Supply chains for perishable items consist of products with a fixed shelf life and limited production/collection; managing them requires competent decision-making. With the objective of placing the learners in the position of decision-makers, we propose the Blood Supply Chain Game which simulates the supply chain of blood units from donors to patients based on a real case study modelling the UK blood supply chain. The Excel-based game is an abstraction of the technical complex simulation model providing a more appropriate learning environment. This paper presents the game's background, its mathematical formulations, example teaching scenarios and the learners' evaluation. The game aims to translate qualitative aspects of a sensitive supply chain into quantitative economic consequences by presenting a process analysis and suggesting solutions for the patient's benefit in a cost effective manner, trying to synchronise blood demand and supply and maximise the value of the whole supply chain. This innovative approach will be instructive for students and healthcare service professionals.

Keywords: Simulation; Empirical Modelling; Decision Analysis; Learning; Business games; Supply Chain Management.

1. Introduction

Product and service supply chains are usually complex and difficult to manage, especially when they concern perishable products with a very high service level. Relevant textbooks and case studies aid learners in the understanding of fundamental ideas about SCM; however, these alone may be inadequate to present the complete picture of supply chains, and most importantly, put learners in the position of managers who have to deal with complex decisions and take responsibility for them. On the other hand, simulation modelling offers a reliable approach to study and evaluate the procedures and outcomes of such supply chains and propose alternatives which can lead to improved performance (Persson and Araldi, 2009; Terzi and Cavalieri, 2004). Simulation models are therefore useful for both modellers and practitioners to offer solutions to observed problems based on quantifiable measures. However, due to the technical complexity of these models it may not be appropriate to introduce them to the learners as they may find it difficult to comprehend and fully appreciate the underlying reasons that justify the use of simulation models (Chwif *et al.*, 2000). Further, the use of models for classroom teaching would require that the learners be familiar with not only the theory of discrete-event simulation (or other simulation techniques which may have been used to develop the model) but also that they have some competence in using the specific simulation tool that was used for model implementation. Adding to this is the cost of the commercial simulation software in question and the requirement to purchase multiple licences for use in the classroom. On these grounds, business games circumscribe an alternative learning approach which assists the understanding of theories, put ideas into action and educates in an active and enjoyable way without prerequisite technical knowledge.

The main characteristics of perishable products are that they have a limited shelf life and thus overproduction and storage of such products is not recommended. They usually have limited production/collection (e.g., donor organs for transplant, blood), or the production/collection is periodic, and the demand is mostly uncertain (e.g., optimal dose and schedule for influenza vaccine is dependent on several factors, including population factors such as age and immunological naivety to the strain) (EuropeanMedicinesAgency, 2007). They also suffer from stock-outs, outdates, discarding costs and for the most part customer returns are not accepted or realistically possible. Moreover, the supply chain of a healthcare perishable product (i.e. supply chains associated with production and delivery of vaccines, blood for infusion and donor organs for transplant) incorporates additional sensitivity aspects such as high order fulfilment due to patient's potentially life threatening situation.

The supply chain of perishable products, in order to succeed in increasing profits/value and to achieve a reduction in costs, usually focuses on rational system planning, improved communication among the supply chain players, well-coordinated and fast distribution channels and the clarification of organizational goals. The major benefits for the consumer are thought to be better availability, fewer stock-outs, fresher product with a longer shelf life, and potential cost savings (Wilson, 1996). These important characteristics are emphasized and play a vital role in our case study which is targeted at a healthcare supply chain of a time-sensitive and life-saving perishable product, namely blood.

The challenges associated with the management of the supply chain of blood products can be further appreciated by referring to the following statements of facts from the U.S. (Whitaker, 2007): the blood supply is frequently reported to be just 2 days away from running out; hospitals report as many as 120 days of surgical delays due to blood shortage; there was an estimation of 8.1% outdated blood units from blood centers and hospitals for the year 2007; there is a high and rising processing cost associated with blood units due to increased testing requirements. The proposed business game attempts to expose these particularities of such a supply chain.

The main focus of this paper is on the development of a business game dealing with the blood supply chain and the game's value to the learners. The conceptual idea and initiative for the construction of the game is derived by a discrete-event simulation model (Katsaliaki and Brailsford, 2007) which identified improvements on the performance measures of a blood perishable product's supply chain. However, due to its complexity, the model was faced with run time problems which were overcome with the use of distributed simulation (Mustafee *et al.*, 2009) . This evolution increased the technical complexity of the model and it was difficult to handle and be comprehended by its users. Therefore, a game-based (spreadsheet simulation) approach was assumed a good solution to cover this gap. The detailed analytical presentation of the blood supply chain simulation game example provides a useful framework for learning about challenges in perishable products supply chain systems. In addition, the concept of templates (that is, Excel Workbooks in the electronic format of the game or data record sheets in its paper version) introduced can be used to build a generic framework for supply chain design of any business operation. The distinguishing feature of this game-based approach is the emphasis given to the integrated system development environment utilizing simulation, to develop a clear recognition of total supply chain cost elements, strengthen integrative management of analytical and problem solving skills and learn about supply chain management challenges.

The game is also useful for research and assessment purposes. The game gives students a real supply chain case study (Katsaliaki, 2008; Katsaliaki and Brailsford, 2007) which resembles the operations and principles of a supply chain taught in the class but has its own particularities. Students need to translate these processes and make decisions to solve the problems of the real simulated case. In particular, the game can assess students' competency of applying the supply chain principles that are taught in class and measure how well the students comprehend the interrelationships between the different function of a supply chain; how effectively use the given, incomplete information to make decisions which improve the chain's performance; and how well they coordinate these processes in order to increase the satisfaction of the supply chain players and their profits. The Blood Supply Chain Game, like other similar games, can help educators answer these research questions.

Various steps of the proposed simulation and gaming research methodology shown in Figure 1 include:

1. Define game objectives in accordance to supply chain theory (such as, balancing supply and demand, push-pull-cycle process view, inventory control mechanisms, distribution approaches, competitive priorities, bull-whip effect, and cost-benefit analysis) and simultaneously in relation to the learning derived from the simulation model (DES) of the real case study.
2. Develop the game by defining its mathematical formulation keeping only the value added points for learners from the simulation model and exclude complexities, to turn it into an education game as a holistic problem based experiential learning supply chain system tool.
3. Implement a paper version of the game and create instructions of a challenging game story with alternative scenarios. Enable validation, in a pilot study, by testing the game objectives after playing it many times with different options and different player's decisions to assess results validity.
4. Implement a computerized version of the game to enhance playability exposure by creating options for changing the difficulty level of the game from deterministic to

probabilistic for learners to develop mastery of supply chain management concepts and principles. Ensure usability of the game with additional supporting factors, including: production of a user friendly interface for easy play, generating supportive graphs for better learners' comprehension, providing options for Save, Restart, etc. and automated guidance for the playing steps. Ensure model verification by testing the game mechanics in different computer specifications to examine software and programming issues, usability and consistency of graphical outputs.

5. Facilitate evaluation and classroom pedagogy. It is vital to determine how the learners react and what knowledge and skills advance by playing this game.
6. Refine the model by looping back to step 1 until learner's feedback suggests target performance levels and research objectives set out for blood supply chain achieved.

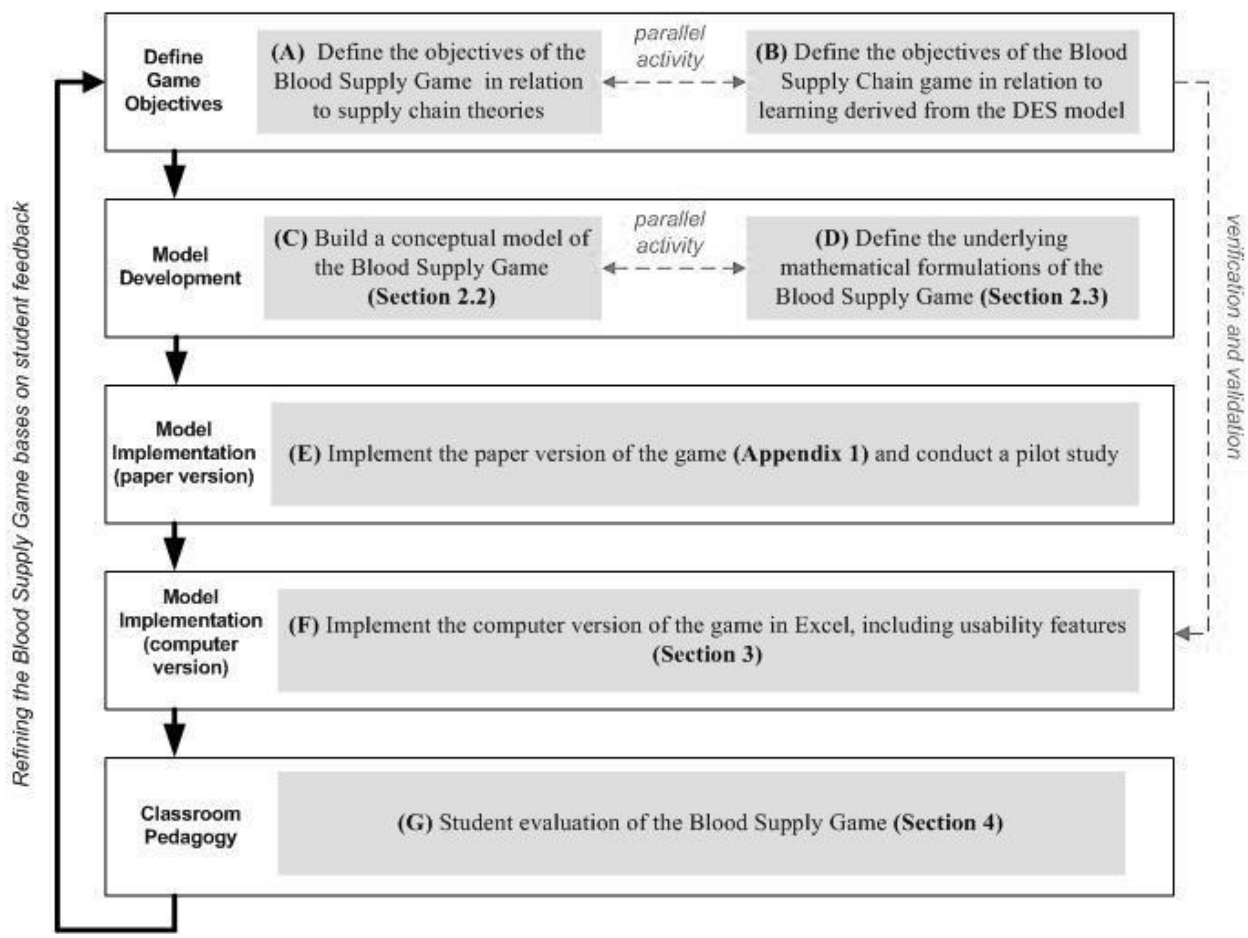


Figure 1: Simulation and Gaming Research Framework

In detail, the remainder of the paper is organized as follows. Section 2 presents a short literature review of the role of business games in teaching and teaching SCM specifically, enumerates the purpose and description of the proposed Blood Supply Chain Game and its simplifications and finally discusses the logic of the game and its underlying mathematical formulations. Section 3 outlines the teaching strategies that can help management students learn the complexities of decision making in relation to supply chains, and to further appreciate and "connect" with the intricacies associated with the supply chain of perishable products. This is complemented by presenting and discussing the results from the use of the game under each strategy together with its potential value in SCM teaching. Section 4 presents the results of the learners' evaluation of the game. Finally, section 5 discusses concluding remarks and extensions to the game.

2. The Blood Supply Chain Game

2.1 The Purpose of the Game

The business simulation-based training provides problem-based experiential learning proficiency which generally is lacking in traditional training methods viz. syllabi, case studies, teaching frameworks for courses, and so forth.

Over the last decades, games of different types have been successfully used for teaching courses like production and operations management (Morecroft and Sterman, 2000; Riis, 1995), business administration (Hoogeweegen *et al.*, 2006), management science (Ben-Zvi and Carton, 2007) and Information Systems (Ben-Zvi, 2010).

Games are used to elucidate the dynamic nature of systems management and for testing new planning principles. Managers need methods to understand how their organization works in order to test policies, discover flaws in thinking, and find hidden leverage points within the complex systems they manage. Through a system simulation, the dynamics of the whole system, not just the individual parts, become apparent. The outcome of current and future situations becomes possible to predict and with this information, managers can focus on the changes needed. The general purpose of these games is threefold: to create awareness and insight from experiencing the interplay of different sections and functions; to teach by creating understanding and knowledge on the basis of try-outs of different planning principles; and to train by providing practical know-how from planning a handling job (Morecroft and Sterman, 2000; Riis, 1995).

In SCM teaching, the most popular game which is part of many SCM curricula is the *Beer Distribution Game* developed at MIT about 25 years ago (Sterman, 1989). Facilitating the students acquiring direct knowledge of the "bullwhip effect" (Forrester, 1958; Geary *et al.*, 2006; Lee *et al*., 1997) and the benefits of information sharing and lead-time reduction. Another game which was developed for teaching SCM is the *Mortgage Service Game* (Anderson Jr. and Morrice, 2000). This is a simulation game designed to teach service-oriented SCM principles with no inventory where backlogs are managed through capacity adjustments. The game demonstrates the impact of demand variability and reduced capacity adjustment time and lead times. Another one relates to the analysis of green supply chain contracts with emphasis on sustainable development through proper pricing and marketing exposure (Barari *et al.*, 2012). This list is not exhaustive but gives a close picture of different games developed in the field.

Table 1 exhibits some properties of the aforementioned games and a comparison is made between these games and the blood supply chain game. The proposed Blood Supply Chain Game demonstrates the following main differences from the above mentioned games: (a) The product is perishable, meaning that timely consumption should be made, otherwise losses will occur in the stock (in other words, the blood has to be transfused prior to the expiration of the shelf life). This is a constraint which is not present in the other games and places a lot of pressure in a highly functional SC. (b) The "production" capacity is finite and predetermined since planning for blood collections is organized well in advance and requires a lot of scheduling and coordination. This gives the SC control to the supplier unlike the other SCs where the power lies with the buyer/consumer. (c) In the Blood Supply Chain Game emphasis is given to the distribution process in search of a fair order fulfilment strategy. The game is played from the point of view of the distributor (who is part of the supplier). The other echelons in the supply chain have specific roles played by the computer. In the other games, but the Beer game, there are not specific roles allocated and therefore the players have an overall control of the SC which is unlikely to be true in reality. (d) The game allows for stocks but no backlogs since the demand (transfusions) is only satisfied at the moment needed. It can be argued that these four differences make the Blood Supply Chain Game particularly suitable for teaching the intricacies of the supply chain, in that students are most likely to encounter them in the workplace.

Table 1: Comparison amongst Games' priorities

Properties/Game Name	**Blood supply game**	**Beer Distribution Game**	**Mortgage Service Game**	**Green SC contracts**
Theory contribution	Supply & demand balance	Bullwhip effect	Service SCM	Sustainable SC
Focus	Order fulfilment & Distribution policies	Order fulfilment	Capacity Management	Pricing & Marketing
Game objective	Maximize profit/value	Reduce costs	Reduce cost	Maximize profit
Supply	Finite/Scheduled	Infinite	Infinite	Infinite
Demand	Non-stationary	Non-stationary	Non-stationary	Non-stationary
Power over to	Supplier	Buyer	Buyer	Buyer
Product characteristics	Perishable and Sensitive	Nonperishable	Nonperishable	Nonperishable
Inventory management	Inventory with no backlogs	Inventory and backlogs	No inventory and backlogs	Not relevant
Technique	Spreadsheet & manual Simulation	Spreadsheet & manual Simulation	System Dynamics	Game theory/Monte Carlo Simulation
Player role	Supplier/distributor	Manufacturer, Wholesaler, Retailer	Not specific	Not specific
Players	Single	Team	Single	Single
Playing mode	Paper and computerized	Paper and computerized	Computerized	Computerized

The purpose of the Blood Supply Chain Game is threefold:

- To improve students'/professionals' understanding of complex principles of supply chains such as variant supply and demand, distribution options, product and market characteristics;
- To evaluate the overall impact of these principles, which is different from the sum of the impact of each one of them;
- To train participants in making better decisions under pressure and in complex situations where an outcome arises from the interaction of multiple factors and interventions.

The game's target learners' group is future industry leaders in management (current operations management students) and current or future healthcare service professionals, particularly, physicians, nurses, technicians and managers of blood banks. The learner must have some prior knowledge of the supply chain and operations management concepts and theories and should apply logical methods for optimizing inventory and transportation allocation. Moreover, it gives them incentive to translate qualitative aspects of a sensitive supply chain into quantitative economic consequences by presenting a process analysis and suggesting solutions for the patient's benefit in a cost effective manner, trying to synchronise blood demand and supply and maximise the value of the whole supply chain.

The game is also useful for assessment purposes on learners' competency of applying the supply chain principles as students' performance on the game is reported and monitored while playing it. There is also a research element in the game activity, giving students the possibility to investigate different strategies in a "near" real case study and take a step forward to brainstorm new ideas of how to better coordinate these processes in order to increase the satisfaction of the supply chain partners/parties and their profits.

2.2 Description of the Game

The *Blood Supply Chain Gam*e simulates the blood supply chain processes shown in Figure 3 of blood collection, processing, testing, supplier's inventory holding, orders, distribution, hospital's local inventory, usage, returns and outdates, together with product and transportation cost, revenue and value functions (in our game the profitability of National Blood Service (NBS) is used as a measure of value since any excess of revenue over cost will be invested back into the NBS; thus, the higher the profit, the greater will be the value derived by the public from the NBS. It therefore follows that the game's objective of profit maximization will also lead to value maximization). For additional information on the NBS simulation model, readers are advised to look into Katsaliaki and Brailsford (2007).

The Blood Supply Chain Game is played from the perspective of the distributor which is the middle player in the supply chain (and who is vertically integrated with the manufacturer-NBS). Rational decisions from this player require deep understanding of the processes of the other players in the supply chain, as well as, the operations of the chain as a whole.

The game is developed in Microsoft Excel (using the VBA programming environment) and is designed for individual play. Instructions on how to download and play the blood supply chain game are available on the authors' website. Additionally, a paper version of the game for class play, with the use of a data record sheet, is described at the appendix.

Figure 2 displays a flow diagram of a high level view of the basic supply chain players of a perishable product, the flow of the product and information. The normal arrows represent product flow, whereas the dotted arrows represent information flow (orders). The main focus is to arrange processes in such a way that outdates are minimized in all parts of the supply chain and the product is sold as freshly as possible. Figure 3 portrays the basic logic of the blood supply chain model which is similar, but, more detailed than Figure 2. *Hospital and Doctors' Orders* in Figure 3 represent *Retailer and Customers' orders* in Figure 2 respectively. The block of boxes of *Storage in Hospital Bank* (Figure 3) is represented with a single box of *Retailer*

Storage in Figure 2 and finally the transfusion decision phase in Figure 3 is represented by a single box of *Sold before expiration* in Figure 2.

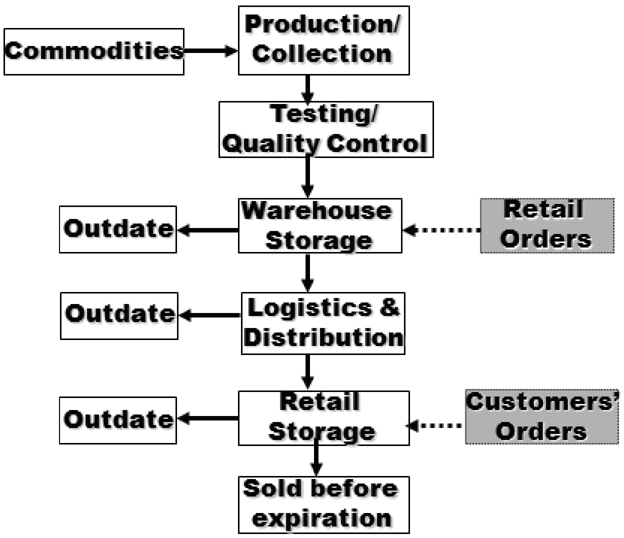


Figure 2: Flow diagram of a perishable product supply chain

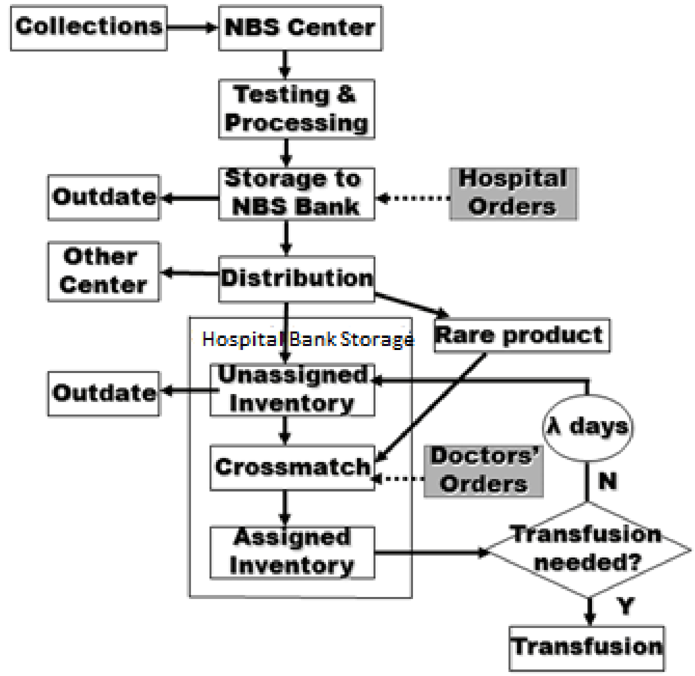


Figure 3: Flow diagram of the blood supply chain with orders from one hospital. Adapted from (Katsaliaki and Brailsford, 2007)

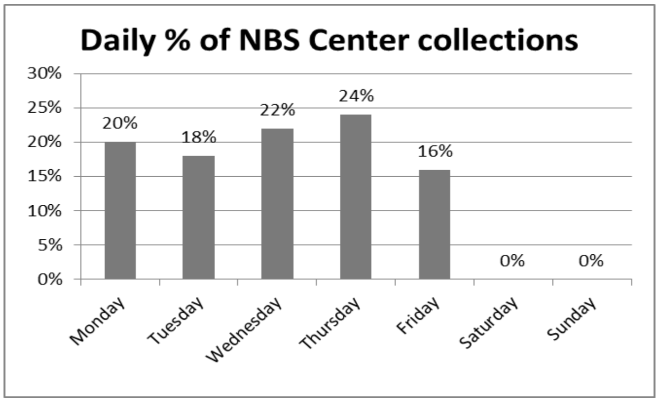
The game-based approach attempted to remove some of the complexity of Figure 3 but captures all the elements presented in Figure 2. Specifically, two main simplifications occur in the game: 1) the compatibility (crossmatch) of the different blood types is ignored as it would make the game very difficult for the player to comprehend and stay focused on its strategic managerial aspects. 2) The perishability of the product is not calculated on a day to day count down of its shelf life but rather on a simplified way of checking for outdates biweekly. This process, although inaccurate, is not completely unrealistic as in hospitals the blood expiration date is not checked daily for all units but only for some before crossmatching for transfusion occurs. The main reason behind the simplification is the runtime problem faced by the initial simulation model (as presented earlier in this section) due to the numerous entities necessary for programming the blood's shelf life count down which ended in the adoption of the distributed simulation approach. To avoid this difficulty and produce a working game a simplified way was used. This does not deduct value from the overall performance of the supply chain as the simplified approach is in agreement with the output of the model which has been validated against the real system. In the paper version of the game the perishability feature is removed as the game is played only for a week to reduce the tedious calculations required from learners.

2.3 Description of the Model

The following section describes the routine processes of the supply chain of blood for a particular NBS center which supplies three hospitals (i = hospital identification number) of different size in terms of blood consumption.

Blood collections from the NBS center are gathered to match the requirements of all three hospitals together. Historic data has shown that weekly collections are approximately 580 units of blood. However, after observation and experts' experience, it was noted the daily collections fluctuate according to the probability distribution shown in Figure 4a. This means that on Mondays, average collections are 20% of the weekly collection of 580 units and so on. During the weekend there are no collections or processing taking place. The processing and testing (Pr) takes a day to be completed and thus blood units are available in the NBS center's blood bank for stocking and shipping in the next morning. This implies that the Monday collection reaches the NBS bank on Tuesday morning; Tuesday collection is stocked on Wednesday and so on. The Friday collection is available only on the following Monday as the service closes on Friday evening and the available processing time is not sufficient for the units to be placed on Saturday in the bank. Unlike collections and processing, NBS deliveries operate on a seven days a week basis.

Hospital Doctors' orders (O_{Dr}) are placed according to patients' needs. Hence, doctors' orders in terms of blood units clearly differ between hospitals, since each hospital performs a different combination and number of transfusions according to the number of patients and needs. From past experience it is known that weekly doctors' requests for the large hospital (H_L) are around 495 units, for the medium hospital (H_M) 300 blood units and for the small one (H_S) 110 units. Altogether 905 units of which the small hospital represents 12% of all doctors' orders, the medium represents 33% of all orders and the large 55%. However, similar to collections, there is a daily fluctuation in doctors' orders which is usually common to all hospitals and is related to the patterns of patient arrivals to hospitals. These daily fluctuations are shown in Figure 4b:



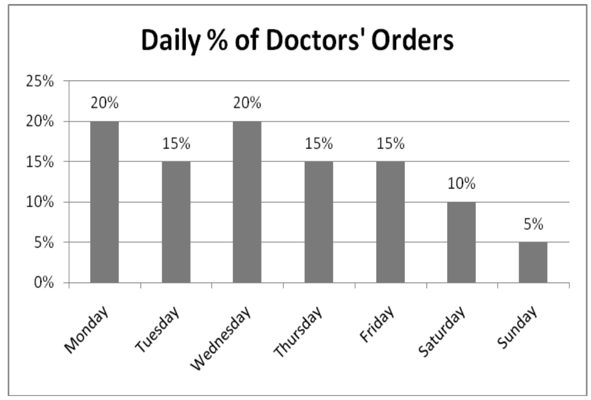


Figure 4a: Daily NBS center blood collections

Figure 4b: Daily % of Doctors' blood orders

Doctors' orders (O_{Dr}) are usually placed once a day in the morning or afternoon. Each hospital checks its stock (S_H) in the hospital bank and satisfies the doctors' orders from its stock otherwise orders from the NBS center stock (S_{NBS}) as many units necessary to fulfil the doctors' request. At the end of the day approximately only 65% of doctors' requests (O_{Dr}) are actually consumed/transfused (T) due to over-ordering for doctors to be on the safe side (a "bullwhip" phenomenon); the remaining 35% of the blood units are returned to the hospital stock and are used together with other residuals to satisfy the next day's orders. For reasons of teaching simplicity we do not consider different types of blood groups or blood groups compatibility issues in the game.

Mathematically, the structure of (1) the individual hospital stock (S_H), (2) transfused units (T) and (3) hospital orders (O_H), are given in Equations 1 to 3 (all measured in blood units):

$$S_H(i,d) = S_H(i,d-1) + I_{NBS}(i, d-1) - T(i, d-1) \quad (1)$$

If:

$$0.65*O_{Dr}(i,d) < S_H(i,d) + I_{NBS}(i,d)$$

$$T(i,d) = 0.65* O_{Dr}(i,d) \quad (2a)$$

Else:

$$T(i,d) = S_H(i,d) + I_{NBS}(i,d) \quad (2b)$$

$$O_H(i,d)= O_{Dr}(i,d) - S_H(i,d) \quad (3)$$

Where I_{NBS}= NBS issues, O_{Dr}= Doctors' orders d= day number and i =hospital identification number

Hospitals' requests in blood units (O_H) come at different times of the day in mixed order, but mainly until 6pm. The center's stock changes during the day as follows: Early in the morning the new processed units (Pr) are added to the previous day center's stock (S_{NBS}). The hospitals orders (O_H) arrive later in the day and the player (distributor) needs to make a decision as to how much of the hospital's order to satisfy (I_{NBS}). The stock goes down by this amount every time an order is issued/shipped to a hospital. Each delivery to the hospital and back costs the distributor (NBS) $47 regardless of the number of units transferred. This cost (C_{Tr}) covers the drivers' pay, fuel and maintenance variable expenses, as well as, amortization costs associated with purchasing the special vans with the freezers. The NBS stock is re-calculated up to three times (for consignments to the three hospitals) after each decision of how much to issue to a hospital is made. Equation 4 computes the new NBS stock (S_{NBS}) at the end of the day, d'.

$$S_{NBS}(d') = S_{NBS}(d) - \sum_{i=1}^{3} I_{NBS}(i, d) \quad (4)$$

Where $S_{NBS}(d) \geq 0$

Unsatisfied orders (UO_H) from the NBS to the hospitals (Equations 5) are considered a major drawback of the NBS service and the approval and rating from the hospitals, public opinion and Ministry of Health diminishes. Moreover, an ultimate dissatisfaction arises when not only hospital orders but patients' needs in blood are left unsatisfied (UP_H) (Equation 6). This means that a patient's life may be at risk because the patient will not get the amount of blood needed during the transfusion process when unsatisfied doctors' orders are high (for over 65% if we assume that this is the amount of over-ordering which is again available for other patients. To incorporate this dissatisfaction into the process of the supply chain there is a loss cost associated with each unsatisfied order (C_{UO}) of $63 and a much higher one of $785 which is associated with an unsatisfied patient (C_{UP}) who did not receive the amount of needed blood (in the real blood SC these costs are related to plasma).

When $O_H(i,d) > I_{NBS}(i,d)$

$$UO_H(i,d) = O_H(i,d) - I_{NBS}(i,d) \quad (5)$$

When $0.65 * O_{Dr}(i,d) > T(i,d)$

$$UP_H(i,d) = 0.65 * O_{Dr}(i,d) - T(i,d) \quad (6)$$

Another point which needs to be taken into consideration is the importance of keeping stock balanced. If NBS stock increases, eventually blood outdates will occur and the stock will then be reduced after the removal of the perished goods. From observing the behaviour of the simulation model it was noted that outdates occur when the NBS stock constantly increases for a number of days and then drops to a lower level, more apparently on Mondays, as outdated units are removed from the bank. From the real system it is known that processing occurs in batches of blood units from Monday to Friday and actually the Thursday collections (the highest in number to make up for the weekend demand, see Figure 4a) are stocked on Friday and are the last to go into the NBS blood bank until the following Monday (Katsaliaki and Brailsford, 2007). If there is more supply than demand for a number of consecutive days (usually more than a week) then a Monday will come in which outdates will be removed from the bank at a higher number than usual, as they will include outdated blood units processed 35+ days that may have expired over the weekend. With the ultimate purpose being to simplify the business game this complex observation was translated in the game in the following way: if the sum of the weekly stock (S_{NBSw}) from Monday to Sunday increases in two consecutive weeks by more than 5%, then 50% of this increase accounts for stock that has been outdated/perished (Pe) (Equation 7).

If: $\frac{\mathrm{SNBSw(di+14) - SNBSw(di)}}{\mathrm{SNBSw(di)}} > 0.05$ (7a)

For d=14 and d= 28

$$Pe(d) = 0.50 * [S_{NBSw}(w) - S_{NBSw}(w-1)] \quad (7b)$$

Where w=week number

This means not only that these blood units have to be subtracted from the NBS stock the next day (Monday) (Equation 8) but also that handling costs occur (C_{Pe}) which are estimated at $47 per outdated unit for discarding the perished blood.

For d=15 and d= 29

$$S_{NBS}(d) = S_{NBS}(d-1) - \sum_{i=1}^{3} Pe(i, d-1) + Pr(d) \quad (8)$$

The functions for the perished units and associated costs are not part of the paper version of the game as this is played only for a week during which the products do not yet perish. This reduced playing period is mandatory due to the tedious manual calculations of the game required from the learners. Moreover, the perishability function is difficult to be incorporated in the data record sheet as this would weaken its appearance.

The NBS pays $157 for PTI of each processed blood unit (Pr) but also loses money because of unsatisfied orders and unsatisfied patients. The NBS revenue (R_{NBS}) is generated by the hospitals which pay the NBS $220 for each delivered blood unit (I_{NBS}). There should be a good balance between the cost of production and distribution and the revenue gathered from hospital purchases. Any profit (P_{NBS}) made by the NBS goes to R&D which is vital for processing and testing breakthroughs which may have direct medical effect. One must also consider that the budget of the hospital is not unlimited.

Equation 9 exhibits the NBS profit function for each day of the game whereas the Total NBS Profit for 28 days that the game lasts is calculated in Equation 10:

$$P_{NBS}(d) = R_{NBS}(d) - C_{PTI}(d) - \sum_{i=1}^{3}[C_{UO}(i,d) + C_{UP}(i,d) + C_{Pe}(i,d) + C_{Tr}(i,d)] \qquad (9)$$

Where C_{Tr} = Transportation Cost and C_{PTI} = Processing, testing and issuing Cost

$$\sum_{d=1}^{28} P_{NBS}(d) = \sum_{d=1}^{28}[(R_{NBS}(d) - C_{PTI}(d)) - (\sum_{i=1}^{3}(C_{UO}(i,d) + C_{UP}(i,d) + C_{Pe}(i,d) + C_{Tr}(i,d)))] \qquad (10)$$

In the beginning of the Blood Supply Chain Game there are 100 blood units stocked in the NBS center bank. There are also 25 blood units in the large hospital bank (H_L), 15 units in the medium hospital (H_M) and 5 units in the small one (H_S). The computerized version of the game is played for 4 weeks (28 days).

3. Teaching approaches and indicative results

The game is developed using Visual Basic for Application (VBA) programming environment (which is a part of most Microsoft Office applications) and uses Excel for storing data, to compute formulas and for graphing functions. With the program, the game is easy to run and fun to play. The only requirement is a computer with Excel for Office '97 (or more recent version of Microsoft Office). The paper version of the game is also developed for class play with the use of data record sheets with small amendments in the formulation of the game. This is described in the Appendix. The structure of the game and the customizability of the parameters allow different hypotheses to be tested under controlled conditions. The ease with which data is recorded and compiled lets players build their understanding as the game progresses. Also, it allows instructors to build a comprehensive database of experimental results. Below we present teaching approaches for playing the game together with some screenshots from indicative results.

Following the logic of the game described above, the aim of the player is to make decisions that maximize the profit of the NBS which is highly related to satisfying as many hospital patients as possible and as many hospital orders as possible. The main question the player has to answer is how much of each hospital's order to satisfy considering its limited stock. At the beginning of the game the players are usually encouraged to satisfy the entire amount of order in the sequence that this arrives to the NBS until stock runs out. The remaining orders will be left unsatisfied and usually this affects the hospital that requests blood last. The players are advised to monitor unsatisfied orders and patients, as well as, occurring costs. They are also advised to examine whether a particular hospital is unhappy with this policy as its orders are left more often unsatisfied than other hospital orders. Therefore, the game is played by satisfying the entire number of orders according to the sequence of their arrival until there is no more NBS stock left.

At the start of the game the player has to decide the game version and the policy/scenario that is to be played. The first screen that the user encounters is shown in Figure 5 ("*Multi-Player Options"* tab is greyed out since it is a functionality to be implemented in later versions of the game). As can be seen from the screenshot below, the player has to decide, (a) whether to play the standard (default) version or the advanced version of the game, (b) whether to play policy one, two or three, and (c) the NBS blood collection for a week. The player can enter a value for (c) only if the player has selected either policy two or policy three. Subsequent to the selection of the various game options, the player is presented with the main graphical user interface of the Blood Supply Chain Game. This is shown in Figure 6.

Figure 5: Graphical user interface of the game options

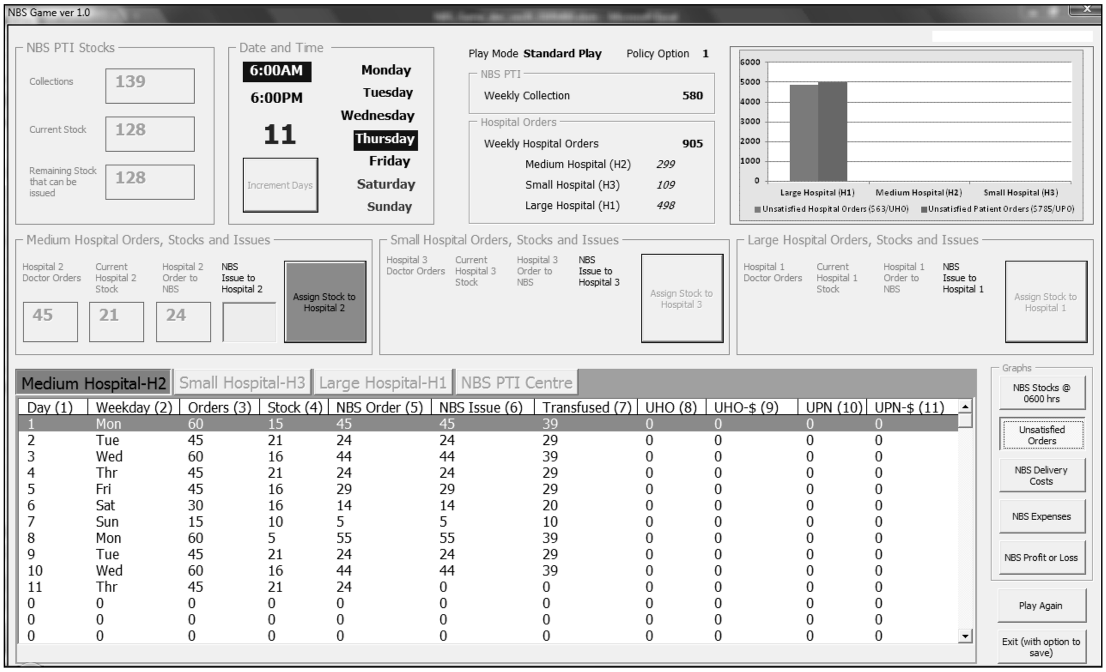


Figure 6: Graphical user interface of the Blood Supply Chain Game

The game options that are selected by the player using the first screen (Figure 5) are now described. The game's scenarios (i.e., policies one, two and three) can be played under two different versions, the standard version and the advanced version. The evolution from a standard to an advanced version of the game corresponds to enhancement of knowledge and the gradual increase in experience. Evolutionary learning has great potential in business training. In the standard version the NBS weekly collection of blood units and the weekly doctors' orders are deterministic and in the first scenario these hold the default numbers of 580 units and 905 units respectively. According to this, the daily blood collections are then determined by the probability distribution of daily NBS center blood collections given in Figure 4a and the probability distribution of daily doctors' blood orders given in Figure 4b. These distributions determine a different number of collections /orders for each day of the week and these patterns are repeated across the weeks. Therefore, every Monday the NBS collects 116 units and doctors' order 181 units, every Tuesday collects 104 units and doctors' order 136 units and so on. Under the other two proposed scenarios the NBS weekly collection is determined in the beginning by the player but once selected the same logic applies for the daily collections throughout the game. The player cannot interfere with the doctors' orders. This process makes the game predictable when thoroughly examined.

In the advanced version of the game the NBS weekly collection and weekly doctors' orders are defined by a random number following a normal distribution. Again the game (or the player for the weekly NBS collection under the two proposed policies) sets the mean value of weekly NBS collections and weekly doctors' orders as in the deterministic version. Then the game's functions automatically generate for each variable a random number from the Normal distribution which is defined by the mean value of the game's (player's) choice. This number of weekly NBS collection and doctors' orders is different for each of the 4 weeks that the game lasts and determines the daily collections/doctors' orders according to Figures 4a/4b probability distributions. As a result, the variables of the game are not predictable (or we could say that are predictable within a wide range) and this makes the game more difficult to manage. However, this version more closely resembles the real system's behavior.

Table 2 tabulates the different game options (i.e., three policies [column 1], each with standard and advanced play options [column 2]) and parameters [columns 3-7] that were earlier explained and will be analyzed by an example in the following sections. The three steps shown in Figure 5 refer to three different columns in table 1 - step 1 refers to column 2, step 2 relates to column 1 and the optional step three is related to column 3. Column 7 refers to the blood allocation sequence for policies one and two. The sequence is as follows: the medium hospital (H_M) orders for blood, followed by the small hospital (H_S) and then the big hospital (H_L).

Table 2: Game options and parameters used

Policies	Game Version	PTI weekly collection	Doctors' weekly orders	Blood Collection Probability Distribution	Doctors' Order Probability Distribution	Allocation of blood (sequence)
Assign stock on demand (policy 1)	Deterministic (standard play option)	580	905	Given - Cannot be changed	Given – Cannot be changed	H_M, H_S, H_L
	Probabilistic (advance play option)	*No user interaction*- STDEV= sqr(**580**)	*No user interaction*- STDEV= sqr(**905**)	Given - Cannot be changed	Given - Cannot be changed	H_M, H_S, H_L
Assign stock on demand with adjusted collection (policy 2)	Deterministic (standard play option)	Collection (***coll***) can be changed STDEV= sqr(***coll***)	905	Given - Cannot be changed	Given – Cannot be changed	H_M, H_S, H_L
	Probabilistic (advance play option)	Collection (***coll***) can be changed STDEV= sqr(***coll***)	*No user interaction*- STDEV= sqr(**905**)	Given - Cannot be changed	Given - Cannot be changed	H_M, H_S, H_L
Assign stock collectively (policy 3)	Deterministic (standard play option)	Collection (***coll***) can be changed STDEV= sqr(***coll***)	905	Given - Cannot be changed	Given – Cannot be changed	Collective allocation
	Probabilistic (advance play option)	Collection (***coll***) can be changed STDEV= sqr(***coll***)	*No user interaction*- STDEV= sqr(**905**)	Given - Cannot be changed	Given - Cannot be changed	Collective allocation

3.1 Standard Version of the Game (Deterministic)

3.1.1 Policy 1 (Assign stock on demand)

Typical results of the deterministic mode of the game are shown below. As we see in Figure 7 the pattern of the NBS stock is repeated every week and is steady. Unsatisfied orders and patients exist in the big hospital (Figure 8). This is realized while playing the game as the big hospital is the last to order from the NBS and sometimes the NBS stock has already been depleted by issuing the full orders of the medium and small hospitals earlier. In table 3 we observe that the NBS generates profit for R&D although there are unsatisfied orders and patients. No blood units have perished and there is a close match between NBS issues to hospitals and NBS processed units. From the transports to hospitals value is understood that each day of the game all three hospitals have requested blood orders from the NBS.

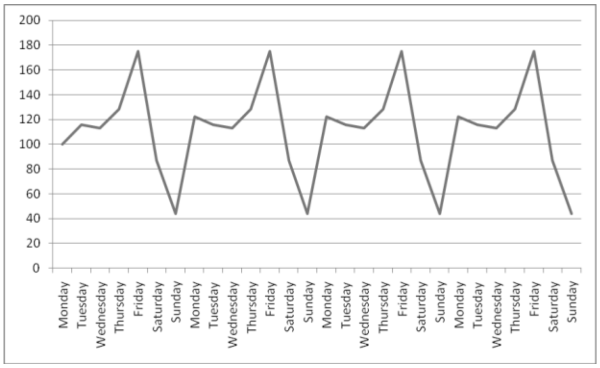


Figure 7: NBS stock units at the beginning of the day (policy 1)

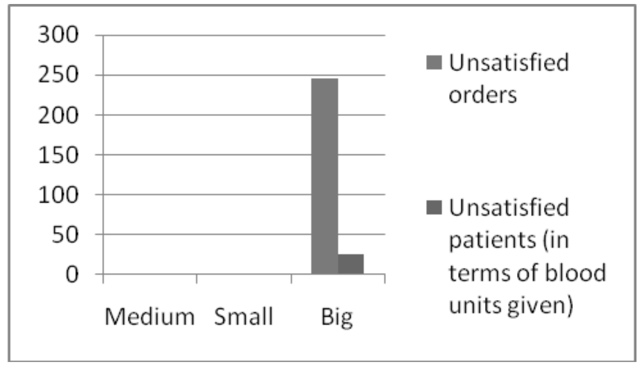


Figure 8: Unsatisfied Orders/Patients blood units per hospital (policy 1)

Table 3: NBS profit calculation (policy 1)

Revenue	**Units**	**Cost**
NBS Issues	2298	$505,560
Expenses	**Units**	**Cost**
NBS PTI	2327	$365,339
Unsatisfied orders	245	$15,435
Unsatisfied patients	25	$19,625
Perished units	0	$0
Transports to hospitals	84	$3,948
NBS profit for R&D		$101,213

After the first results are shown on the computer screen and relevant comments are made by the learners and instructor, the players are encouraged to play the game and decide on how much of each hospital orders to satisfy. In this case results depend upon how well the player has understood the process of the supply chain. However, although the values are deterministic and all variables can be predicted with appropriate calculations, due to the complex interconnection of these variables, some players may get the impression that there is some randomness in the process of hospital orders that cannot be easily predicted.

3.1.2 Policy 2 (Assign stock on demand with adjusted collections)

The players may then be advised to follow other policies to correct the problems. A suggested one is to try to collect more blood and thus satisfy more hospital orders. The player can change the number of units collected per year by the NBS. The results depend again on the value of this number. Below one can see results when choosing to collect 15% more than the initial 580 units, thus, around 670 units per week. The results shown in Figures 9 and 10 and Table 3 are not satisfactory. The NBS stock (Figure 9) in the duration of two weeks' time has an increasing trend and then falls due to perishable units being removed from the bank. This latter produces a waste of 578 blood units (see Table 4). The distance between processed and issued units has increased, as well as, the number of unsatisfied hospital orders and patients in all hospitals. These cause overall loss of $46,919, a 146% decrease in profit from policy 1. Therefore, increased NBS collections do not satisfy more hospital orders because of the complex mechanisms of the system and the perishability of the product. However, the player may be encouraged to try other smaller increases or decreases of NBS collections in order to get a more optimal match between NBS stock and issued units.

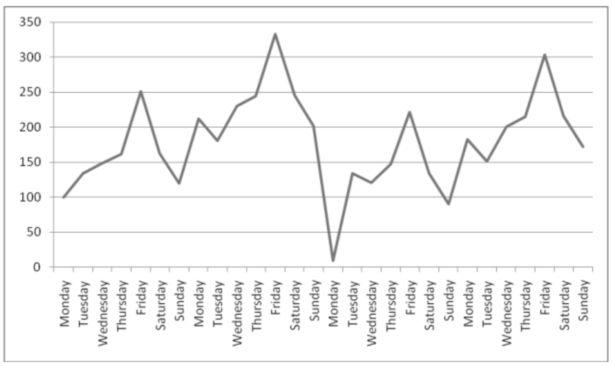


Figure 9: NBS stock units (policy 2)

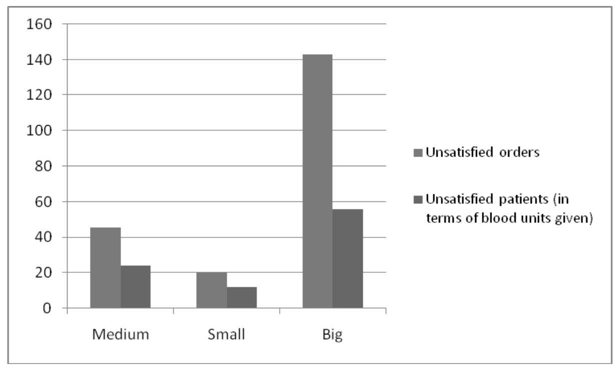


Figure 10: Unsatisfied Orders/Patients blood units per hospital (policy 2)

Table 4: NBS profit calculation (policy 2)

Revenue	**Units**	**Cost**
NBS Issues	2231	$490,820
Expenses	**Units**	**Cost**
NBS PTI	2673	$419,661
Unsatisfied orders	208	$13,104
Unsatisfied patients	92	$72,220
Perished units	578	$28,900
Transports to hospitals	82	$3,854
NBS profit for R&D		-$46919

3.1.3 Policy 3 (Assign stock collectively with adjusted collections)

Following this disappointment the instructor can try to elicit from the players new strategies which could follow as distributors of this supply chain to improve results. This can happen by allowing them to interfere with the logic of the game more drastically. A new distribution strategy that can derive from this brainstorming is the following:

The NBS-distributor can exercise more control over the hospitals. It could delay shipping until all orders from hospitals have been placed and then decide on the units to be issued in each hospital. It could also request that hospitals should place orders until e.g., 2 pm otherwise no delivery will take place on the same day (nevertheless we should note that hospitals may not place orders every day as they may satisfy doctors' orders from their own stock). Then the decision maker (distributor) can work out a fair policy to satisfy all hospitals taking into consideration its total NBS stock for the day and the total hospital orders for the same day. Such a fair policy could be that all orders are satisfied by an equal proportion (Equation 11). However, under certain circumstances (for example, urgency) this proportional mechanism may not be appropriate in real life.

If: $S_{NBS}(d) \leq \sum_{i=1}^{3} O_H(i,d)$

Then: $a = \frac{S_{NBS}(d)}{\sum_{i=1}^{3} O_H(i,d)} \cdot 100\%$

And each hospital is receiving:

$$I_{NBS}(i,d) = a \cdot O_H(i,d) \qquad (11)$$

In this case the transportation cost will also differ. Following this distribution policy NBS can use the multi-stop transport mode which costs only $78 round trip to satisfy deliveries to more than one hospital. However, if only one hospital places an order for a day then this cost is back to $47 round trip. If returns of unused or perished units from hospitals to the NBS were allowed, then these could be incorporated in the same itineraries (return trips) for further reduction in the transportation cost. However, in the particular case study returns are prohibited by legislation and perished units are safely disposed by hospitals.

Results from this option are shown in Figures 11 and 12 and Table 4. (The number of collections is decided by the player. For the results below the initial scenarios' collections of 580 weekly collections were used). Under these circumstances NBS stock is stable again. In Figure 12 surprisingly we observe a large number of unsatisfied orders for all hospitals but no unsatisfied patients. This is the effect of satisfying a proportion of each hospital's orders and although for each hospital some of the orders are undelivered overall there is steady stock in the hospital's bank to satisfy patients real needs. The NBS also makes a bigger profit than in the initial scenario by 20%. Some savings are also observed due to the use of multi-stop transport; only 28 milk runs take place instead of 84 star-like transports in the first scenario.

The players can be asked to propose further solutions to this supply chain that may improve its overall performance by being able to interfere in the processes of the other echelons of the supply chain too, i.e. change decision rules from the hospital side. These recommendations can be used to extend the game by allowing more policies to be tested and players to be decision makers of more echelons in the supply chain.

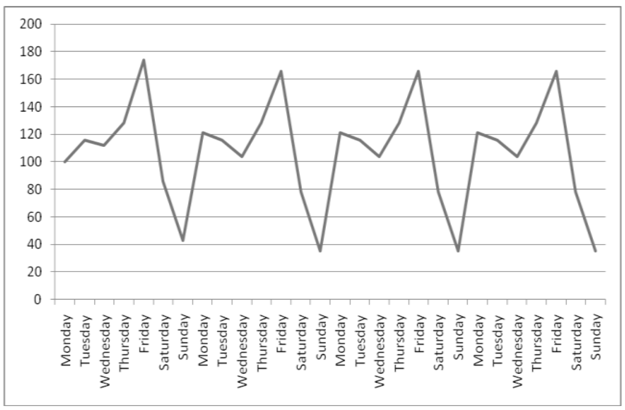


Figure 11: NBS stock units (policy 3)

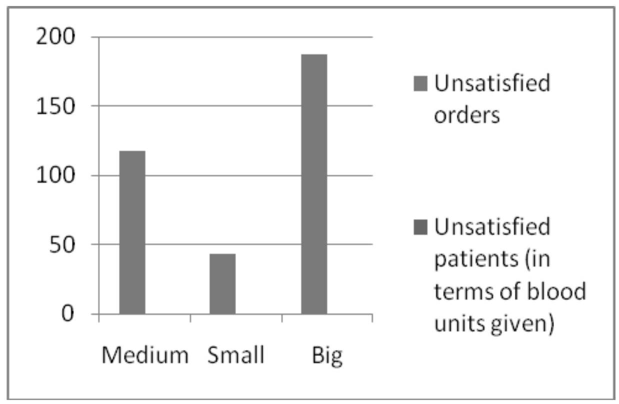


Figure 12: Unsatisfied Orders/Patients blood units per hospital (policy 3)

Table 5: NBS profit calculation (policy 3)

Revenue	**Units**	**Cost**
NBS Issues	2323	$511,060
Expenses	**Units**	**Costs**
NBS PTI	2327	$365,339
Unsatisfied orders	348	$21,924
Unsatisfied patients	0	$0
Perished units	0	$0
Transports to hospitals	28	$2,184
NBS profit for R&D		$121,613

3.2 Advanced Version of the Game (Probabilistic)

The game can then be played in its more advanced version, in which some of the decisions are not deterministic but stochastic as earlier explained. This latter is accomplished by incorporating random variables regarding the values of weekly NBS collections and doctors' orders. This is achieved in excel by adding the "NORMINV(RAND(); mean; SD)" formula. This advanced option of the game is only available in the computerized version.

With the selection of common random number streams for the aforementioned variables the game would confront noisy conditions. Unfortunately, this added variability and the noise that is created around the variables makes their behavior more unstable and their patterns more unclear to identify. This also makes the processes more complicated for the players to understand. The results of the game under the three policies explained below will now be very different between players of the same game and the performance of the system cannot be compared by playing the game only once. The instructor should be aware that the result of any player alone is not of much value as this can vary from another player's result under the same policy. However, it is worth looking at multiple plays of the same policy. An easy way to gather these results and demonstrate them in the class is to aggregate the results from all players who are only requested to play the game once. To illustrate system behavior under the three policies, let us examine the average result of the NBS profit by playing the game for 50 times (Table 6). We see that the average values of the three policies are not similar to the ones demonstrated under the standard version of the game. This may be due to the wide distribution from which we generate values for the weekly NBS collections and doctors' orders denoted also by the high Standard Deviation (STD) values of the 50 runs (Table 5). It may also require playing the game many more times to get more accurate average results. However, the direction of the results according to these three policies is more or less the same. The percentage change between the first and the second scenario depicts a loss of 256% and between the first and the third scenario a gain of 27%. Under the deterministic version of the game these changes were -146% and 20% respectively.

Table 6: Average NBS profit calculations of Advanced play

Advance Play	Policy 1	Policy 2	Policy 3
Average NBS Profit	$36,310	-$56,792	$46,066
Percentage change	-	-256%	27%
STD	$42,120	$37,743	$36,436

The value of the latter version of the game is to demonstrate that the existence of variability which is a normal cause in such business processes makes it very difficult for managers to comprehend the performance of the system. It requires long, thorough observations, a lot of data and working experience in the organization in order to be able to identify the parameters, that if changed or introduced, could bring a better result in the long run.

We suggest that a feedback session be conducted after the Blood Supply Chain Game is played under all recommended strategies. Providing aggregated results (similar to those given above) increases the educational value of the game since the participants learn from their own results as well as the results of others. Additionally, they can observe trends in the data, which is especially important for understanding the process of improving performance measures and SC effectiveness.

The results from the different scenarios were validated against results from the original simulation model built for the real UK blood supply chain (Katsaliaki and Brailsford, 2007). Although the results are not directly comparable due to simplifications made for the game version, the result patterns among the scenarios are similar.

4. Discussion

An evaluation of the game will follow in this section. The aim of this exercise was to reflect on the learning experience and the new knowledge gained by the participants playing the Blood Supply Chain Game.

At first, the authors and a small sample of learners in a pilot study played the paper version of the game followed by the computerized version. The evaluation of the game's paper version was conducted in comparison to the computerized-version against some of the gaming research methodology characteristics presented in Figure 1 and others. Table 7 summarizes the advantages and disadvantages of each playing method.

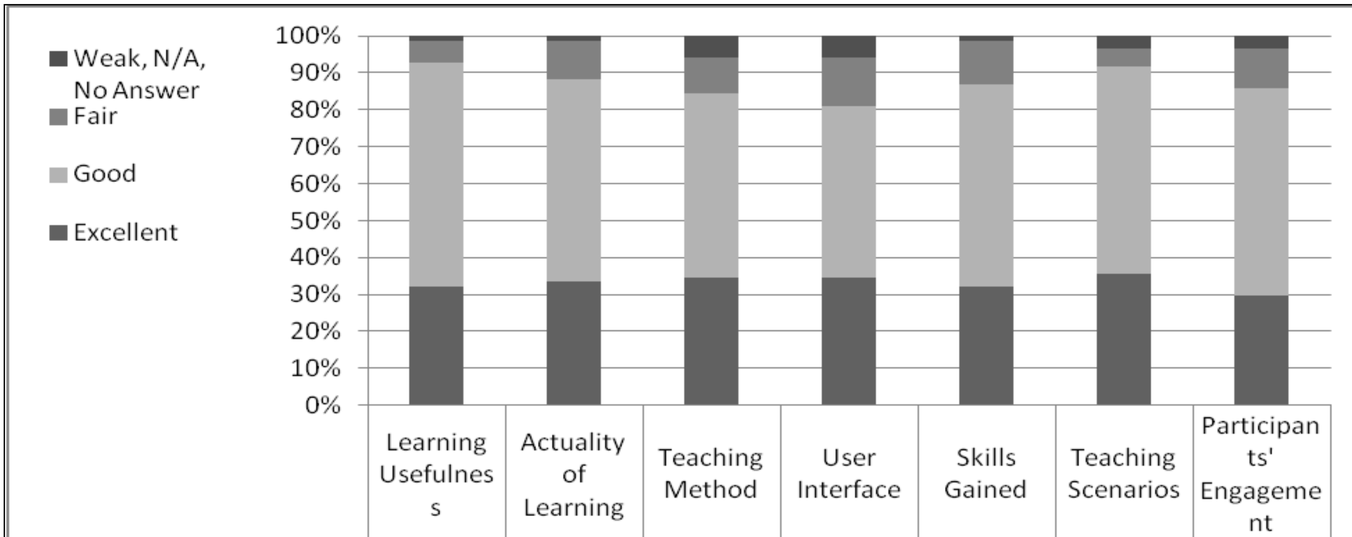
Table 7: Comparison between paper and computerized version of the game

	Paper version	**Computerized version**
Simplicity /mobility	Play everywhere	Play only in a computer lab
Value -added functions	No perishability function	All necessary functions included
Playability exposure	Only deterministic policies Playing period: 1 week	Both deterministic and probabilistic options/scenarios Playing period: 4 weeks
Usability	Difficult to handle calculations and correct mistakes	Automated functions for incorrect values and instructions on demand
Support	Only from instructions	Advanced supporting factors (graphical outputs, automated calculations, Save and Restart functions)
Validation / Scenario comparisons	Hard	Easy (play many times in less time and save results for comparison)
Time to play	~3 hours	~2 hours

It is apparent that the paper version has the advantage of being played in class with no tools other than the instructions and the data record sheets. The instructor needs to print many data record sheets for each student if different policies are to be tested and also to account for mistakes and scraped data record sheets. There is also no need for the learner to have any knowledge of computers and spreadsheets. So, overall the requirements in instruments and players' prior knowledge are less in the paper-version of the game. Other than these, no other advantages are exemplified by the paper version of the game against the computerized one. The paper version is recommended to be played only for a week due to the tedious manual calculations required from the learners. As a consequence, it lacks the perishability function (blood units do not perish within a week) which reduces the impact on the results when the different policies are tested (especially policy 2). It also lacks the probabilistic mode of the identified policies and therefore hinders the learners from developing mastery of the game and fully comprehending the concepts the game attempts to teach. Both these disadvantages distance the game from the real case. Moreover, in the paper version of the game it is far more difficult to correct mistakes realized at a later time while playing, whereas in the computerized version there are automated notifications of impossible values and instructions while playing to help learners with minimizing mistakes. Additionally, the paper version is supported only from the data record sheets and the instructions (and/or instructor) which are developed in a way that try to guide the learner through the many calculations. However, the computerized version offers more supporting factors, such as, automated calculations; automated graphical outputs which are developed while playing the game to monitor progress; the Save function which allows for a pause and ensures a kept file of that played scenario for easier later comparison with many other scenarios and aggregated feedback on performance. Finally, the paper version of the game is more time consuming as calculations are made manually. It requires around three teaching hours (as opposed to two for the computerized version) including introduction to the case and playing the three presented scenarios. Overall, it seems that the paper version of the game has fewer requirements to start with but less support while playing it. The results of the paper version of the game are identical to the indicative results occurring in the first week of the playing period for the deterministic policies of the computerized game, if the same instructions are followed as the ones presented in the teaching approaches section 3.

Further to that initial evaluation of the different playing modes of the game, the computerized version of the game was then evaluated by learners for various properties. The evaluation consisted of interaction with the learners in two separate sessions. The first session included a presentation and explanation of the game's goals and specific instructions to play the game; the second session was held subsequent to game-play. It focused on the game evaluation from the learners through the use of questionnaires. The motive was to have participants share their feelings and opinions about the learning experience.

In detail, the Blood Supply Chain Game was evaluated by 84 postgraduate students, realizing the roles of blood donors and healthcare service professionals such as, health administrators, or doctors, studying an Operations Management module in a university based in UK. The game was played in a two hour lab-based seminar assisted by two tutors. The students were split into five different seminar groups, with each seminar beginning with a 35-40 minute presentation describing the NBS supply chain, the game and its objectives. A lab sheet was distributed in the seminar that contained the necessary information that the students needed in order to play the game. Adding a competitive element to the game, the students were asked to record the scenarios that they were playing, with the objective that the student that secured the most profit, with the least unsatisfied orders and unsatisfied patients, was the winner. Throughout their game-play the participants had the opportunity to seek further clarification from the course tutor and the module lecturer and to discuss the results of their play. This interaction allowed the students to reflect on the outcome of their decisions and to experiment with alternate strategies for improved understanding of the blood supply chain system. At the end of the lab-based seminar the students completed an evaluation form comprised of 14 questions based on a Likert scale (1 = excellent, 2= Good, 3=Fair, 4=Weak, 5= N/A, 6=No answer). Figure 13 shows the overall scores for the 7 most important questions for the game and its teaching value. The answers given in the scales 4, 5 and 6 were merged due to their small values to make the figure more legible.



	Learning Usefulness	Actuality of Learning	Teaching Method	User Interface	Skills Gained	Teaching Scenarios	Participants' Engagement
Weak, N/A, No Answer	1.19	1.19	5.95	5.95	1.19	3.57	3.57
Fair	5.95	10.71	9.52	13.10	11.90	4.76	10.71
Good	60.71	54.76	50.00	46.43	54.76	55.95	55.95
Excellent	32.14	33.33	34.52	34.52	32.14	35.71	29.76

Figure 13. Main results of evaluation

The values measured by the questionnaire (and displayed in Figure 13) are now discussed in more detail; the objective is to provide some insights to the reader. The "*learning usefulness"* reflects the rating of the training game in terms of helping participants learn skills and concepts that are applicable to the business environments. The "*actuality of the game"* refers to the roles in the game (e.g., supplier, distributor and retailer) and whether they relate to easily recognizable real-world counterparts. The "*teaching method"* rates the game as a teaching medium (lab game). The "*user interface"* refers to the user-friendliness of the developed Excel-based application and the adequacy of the game graphics. The "*skills gained"* measures the participants' understanding of the process of decision making and of using software for this purpose. The "*teaching scenarios"* rate the participants' comprehension of the game's scenarios (i.e. policies 1, 2, 3 and standard/advance play – please refer to Figure 5) and their usefulness. Finally, the "*participants' engagement"* compares the learning experience through the teaching game instead of rote-memory learning activities.

The excellent and good scores together have shown a more than 85% satisfaction from the players of the game in all questions except from the user-interface which scores a bit lower (81%). This is something the authors can reflect on for further improvement. Learning usefulness scored as high as 93%. The weak scores fluctuated at very low levels between 0% and 3.5% for the teaching method. Other questions in the evaluation form regarded the game debriefing, modification functionalities, learning and playing time, etc. In all these questions the Excellent and Good scores together fluctuated from 82% to 92% scores; this is similar to evaluations of other educational simulation games in healthcare (Hubble *et al.*, 2011) and business (Hoogeweegen *et al.*, 2006). On the whole, in the class discussion students agreed that playing the Blood Supply Chain Game is a valuable and a fun learning experience.

For the authors the debriefing process was also extremely positive and influential for game revision and establishment of new game scenarios. A significant observation gathered during debriefing was the fact that participants acknowledged having understood concepts to which although they had been exposed before in theory, they had not really comprehended in practice. Learning the factors involved in perishable product supply chain was a general accomplishment of the game in all sessions played.

In the future we will attempt to introduce the paper version in the class and evaluate the participants' learning experience in a similar way to the computerized version in order to accomplish a fruitful comparison.

5. Conclusions

The conclusions section is organized over three dimensions; the Blood Supply Chain Game's contribution to research, its practical implications and its limitations which indicate issues for further development and future work.

One contribution to theory of the blood supply chain game is the game's ability to facilitate students and professionals to acquire knowledge of the push-pull and cycle process view of a supply chain [i.e. push process: blood collection system and stocking both in the NBS and hospitals' banks, pull process: doctors' ordering ; cycle process: information (orders) from doctors to hospital bank; hospital bank to NBS bank, information on availability; product move (blood unit issues) from collections to NBS bank, from NBS bank to hospital banks, from hospital banks to patients, from transfusion area back to hospital bank; money transactions: hospitals pay NBS for issues, NBS costs for processed blood units, transportation, shortage cost, ethical cost]. Learners also get acquainted with inventory control practices [i.e. balancing supply and demand through collection size, checking the lead time on processed units placed in stock, monitoring stock progress in NBS and hospital banks, and dealing with perished units assuming, almost, a FIFO order] and with transportation assignment techniques [i.e. issues to individual hospitals and options of start like and multi-stop transport]. The bullwhip effect is also experienced in the supply chain (due to doctors over-ordering approach and blood units looping back to hospital banks from transfusion areas) which learners could be asked to tackle by suggesting ways to mitigate the problem, such as, improving coordination and information sharing amongst the SC actors (i.e. recommend transfusion protocols for different types of surgery and blood disorder disease). In addition, learners are also exposed to the competitive priorities of operations strategy, such as costs (incurring from processed blood units, transportation costs, shortage cost-unsatisfied orders, ethical costs-unsatisfied patients) , quality (shelf-life of product), flexibility (different transportation modes) and dependability (fair issuing to hospitals of a scarce product). They also practice a kind of cost-benefit analysis through the use of the objective (profit) function of the SC. Another contribution of this research is that the combination of simple inventory theory and simple management procedures is the key to successful blood inventory management (i.e. no complicated optimization techniques are required). Approximations and heuristics, combined with experience, are the basis for decisions in blood inventory management. A close focus on shelf-life along with an acute awareness of its importance to the operation of the blood supply chain facilitates this decision-making and interpretation process.

We have created a model to help learners understand perishable supply chain management; discover flaws in thinking; and how to make effective decisions in a complex supply chain system environment. We introduced a game-based empirical approach to decision making that has two important characteristics, namely, product perishability and limited product collection/production. We chose to model a specific perishable product supply chain application (namely, supply chain of blood) as opposed to using a generic model since the former has much greater instructive value because participants are more likely to assume the roles within the game and make the simulation more closely mimic reality (Anderson Jr and Morrice, 2000).

The game is unique as it is the only business game, to our knowledge, which deals with the supply chain of a life sensitive perishable product with different priorities than the usual business games of its kind. The game illustrates the complexity of decision making in a special make-to-stock supply chain environment and is targeted equally at business and healthcare students, the healthcare professional and the wider audience. The game also serves as a decision support system to enable the thinking and decision-making towards more efficient supply chains. The supply chain's performance is based on "profitability" as a monetary value derived from the associated operations costs, fulfilment of orders, and the satisfaction of hospital patients, therefore, translating qualitative aspects to quantitative economic consequences in the problem analysis and suggested scenarios. This allows participants to understand the results of their decision-making. These characteristics are often displayed in products that are associated with various domains, e.g., healthcare (blood units, donor organs), perishable consumer goods (fresh fruits and vegetables, milk). Thus, our game can portray the supply chain of other perishable products, albeit with some modifications to the program logic, for instance, to integrate auctions, which is common in other perishable products trading where the free market balance supply and demand through price.

The structure of the game and the customizability of the parameters allow many different business and operational issues related to a supply chain can be analysed under controlled conditions. The blood supply chain model not only provides a framework for learning for both academia and managers but the concept of templates introduced in this paper also can be used in any business operation to design their supply chain(s) in order to achieve synchronized material flows.

The three selected scenarios of the game and the advanced play identified the following main points respectively. The first point was to illustrate the supply chain dynamics resulting from different orders and stock distribution. The second point was to illustrate the fragility of balancing supply and demand of a perishable product. The third point was to identify simple practices that improve or deteriorate the supply chain performance within the given circumstances. The stochastic version demonstrated how variability in the supply chain's parameters makes the supply chain's performance trends more difficult to recognise according to the decision made.

The practical implications are presented in this and next three paragraphs. The game is based on a simulation model of a real case study describing the UK supply chain of blood which was developed using a commercially available simulation software. The model offered alternatives and solutions for improving the particular supply chain. However, the technical difficulty of the created simulation model made it infeasible to introduce the model in a learning environment. An alternative was to provide the learners an abstraction of the simulation model by developing a) first the paper version of the game with the use of data record sheets for disseminating the basic SC notions of the particular chain to the learners in a simple way with no special requirements followed by b) an object-oriented Excel-based game with Visual Basic applications which is simple to use by the learners and requires them to make decisions pertaining the supply chain of blood just by clicking a few buttons and observing the graphs and tables with numbers.

Some of the game rigors are that processes are not too simplistic and the assumptions made are logical without compromising much of the complexity involved in the process, while avoiding inclusion of trivial or too multifaceted information at the same time.

The paper presents a survey conducted by the authors to capture the participants' views on the game. The evaluation scores show 85% satisfaction and above in various aspects of the game which clearly demonstrate that the players have enhanced their learning experience through the game. Further, a sample of typical players' results from the classroom showed how effectively players can utilize the available information to balance supply and demand and uniformly reduce end-user dissatisfaction in crucial medical situations while trying to manage costs. We also demonstrated the difficulty in achieving this in noisy conditions with varying and unpredictable parameters such as, donors' blood collections or patients' blood needs.

By playing the different game scenarios, participants should improve their understanding of the game and the game's performance. The scenarios help the participants to gradually realize how the supply chain processes and overall supply chain's performance are interrelated and therefore use the available information "both in a statistical sense and relative to an optimal benchmark" (Anderson Jr and Morrice, 2000). The players' satisfaction from the proposed scenarios reached 92%.

Nonetheless, starting with this game there are a number of limitations which indicate plentiful future research directions for gaming research and improved supply chain design for perishable products. Although there are a few different scenarios available in this version of the game, future development of the game will expand this feature and focus on the design of additional scenarios. For example, we can introduce the fact that more collections also require additional marketing campaign expenses to attract more volunteers. This increases the cost per unit. In addition, the model could also incorporate decisions made from the hospitals, such as spending on blood and optimal stock and perishability considerations.

The thinking behind the Blood Supply Chain Game can be easily modified to simulate a supply chain with a different incentive and information structure in order to give emphasis on other crucial parts and dynamics of different supply chains; for instance, by extending for emergency and relief logistics requiring time criticality, application of JIT lean principles, and large-scale efforts. Incorporating emergency and relief logistics to Blood Supply Chain is capitalizing on Little's Law, the most fundamental principle of operations management. This law indicates that time-based operation and lean operation are two-sides of the same coin. It would be interesting to expand the model to cover product variations, establish benchmarks for results comparison and also examine hospitals not served that may suffer from reputation problems and consequent reduction in patients and demand for blood products.

The proposed model mostly relates to managing inventory, operational efficiency and also matching product demand with supply for perishable products. The model does not incorporate a scenario regarding network/distribution channel. Another limitation of the proposed game as a learning tool is that users may potentially focus on winning the game instead of fully understanding the system. Moreover, the absence of team play is an issue which needs to be addressed in the future enhancement of the game. We envision developing a multi-player version of the model wherein multiple players will be able to collaboratively play the game over a network similar to the Beer Distribution Game. We aim to add this feature not only in the computerized version of the game but also in its paper version, which can be easily adopted for class play with no special facility needs.

Overall, we hope that this learning method will be instructive for students and healthcare service professionals and other similar approaches will follow to enhance such pedagogical techniques.

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Appendix

The Blood Supply Chain Game
(paper version)

Instructions

The Blood Supply Chain Game simulates the supply chain of blood units from donors to patients. (Blood Centre-Distributor, Hospital - Doctors and patients).

The player takes the role of the distributor. The main question that the player has to answer is how much of each hospital's order to satisfy considering its limited stock. The aim of the player is to make such decisions that maximize the outcome of the National Blood Service (NBS) which is highly related with satisfying as many hospital patients as possible and as many hospital orders as possible.

The game's scenario is described below. The learners must read the case study and be provided with the data record sheet. They will need to fill it in by calculating the necessary elements (blood units and costs) row by row, day by day for 7 days as they occur in the simulated game and find the aggregated SC profit/loss for that month. The game is played over a 2/3-hour class. It is recommended as a group based activity

The case study

In this exercise, each player will be faced with the routine processes of the supply chain of blood for a particular NBS Centre which supplies three hospitals of different sizes (in terms of blood consumption).

The regional NBS Centre collects blood from donors trying to match the requirements of all three hospitals in its territory. Historic data have shown that weekly collections are approximately 580 units of blood. However, the daily collections fluctuate according to the probability distribution shown in Figure 1a. This means that on Mondays, average collections are 20% of the weekly collection of 580 units and so on. During the weekend no collections take place. The collected blood is then processed and tested for about a day and thus blood units are available in the NBS Centre's blood bank for stocking and shipping the next morning. This implies that Monday collection reaches the NBS bank on Tuesday morning; Tuesday collection is stocked on Wednesday and so on. Friday collection is available only on the following Monday. Unlike collections and processing, NBS deliveries operate on a 7 days a week basis.

Hospital Doctors' orders of blood are placed according to patients' needs. Hence, doctors' orders in terms of blood units clearly differ between hospitals, since each hospital performs a different combination and number of transfusions. From past experience it is known that weekly doctors' requests for the large hospital (H_L) are 495 blood units, for the medium hospital (H_M) are 300 blood units and for the small (H_S) one are around 110 units; 905 units altogether of which the large hospital represents 55% of all doctors' orders, the medium represents 33% of all orders and the small 12%. However, similar to collections, there is a daily fluctuation in doctors' orders which is usually common to all hospitals and is related to the patterns of patient arrivals to hospitals.

These daily fluctuations are shown in Table 1 for NBS collections and in Table 2 for Hospital doctor's orders:

Table 1: Daily NBS Centre blood collections

Day	**NBS Total Supply**	
	Collections %	*Collection (Units)*
M	20	116
Tu	18	104
W	22	128
Th	24	139
F	16	93
Sa	0	0
Su	0	0
SUM	**100**	**580**

Table 2: Daily Doctors' orders for blood units per hospital

Day	**Large Hospital (H_L)**		**Medium Hospital (H_M)**		**Small Hospital (H_S)**	
	Demand %	*Demand (Units)*	*Demand %*	*Demand (Units)*	*Demand %*	*Demand (Units)*
M	20	99	20	60	20	22
Tu	15	74	15	45	15	17
W	20	99	20	60	20	22
Th	15	74	15	45	15	17
F	15	74	15	45	15	17
Sa	10	50	10	30	10	11
Su	5	25	5	15	5	6
SUM	**100**	**495**	**100**	**300**	**100**	**110**

Doctors’ orders are usually placed once a day in the morning. Each hospital checks its stock in the hospital bank and satisfies the doctors’ orders from its stock; if not sufficient then it places an order to the NBS Centre for as many units as it is necessary to fulfill the doctors’ request. Nevertheless, at the end of the day approximately only 65% of doctors’ requests are actually consumed/transfused; this is due to doctors’ over-ordering to be on the safe side in case of complications during e.g. surgery. The remaining 35% of the blood units are returned to the hospital stock and are used to satisfy the next day’s orders.

Hospitals’ requests in blood units come in at different times of the day. Usually each hospital follows its routine order process every day. The Centre’s stock changes during the day as follows: Early in the morning the newly processed units are added to the previous day Centre’s stock. The hospitals’ orders arrive later at the day and the player (distributor) needs to make a decision on how much of the hospital’s order to satisfy. The stock goes down by this amount every time an order is issued/shipped to a hospital. Each delivery to the hospital and back costs the distributor (NBS) $47 regardless of the number of units transferred. This cost covers the drivers’ pay, fuel and maintenance variable expenses as well as the fixed costs of purchasing the special vans with the freezers. The NBS stock is re-calculated up to 3 times after each decision of how much to issue to a hospital is made.

Unsatisfied orders from the NBS to the hospitals are considered a major drawback of the service and the approval and rating from the hospitals, public opinion and Ministry of Health diminish. Moreover, an ultimate dissatisfaction arises when not only hospital orders but patients’ needs in blood are left unsatisfied. This means that a patient’s life may be at risk because the patient will not get the amount of blood needed during the transfusion process due to over than 65% unsatisfied doctors’ orders. To incorporate this dissatisfaction into the process of the supply chain there is a loss cost associated with each unsatisfied order of $63 and a much higher one of $785 which is associated with an unsatisfied patient who did not receive the amount of needed blood.

Another point that needs to be taken into consideration is the perishability of blood. If NBS stock increases too much, eventually blood outdates will occur and the stock will be reduced due to the perishability of the good. From experience it has been noted that if the sum of the weekly stock from Monday to Sunday increases in two consecutive weeks by more than 5%, then 50% of this increase is stock that has been outdated/perished.

This means not only that these blood units have to be subtracted from the NBS stock next day (Monday) but also that handling costs occur every other Monday which are estimated to $47 per outdated unit for discarding the perished blood.

The NBS pays $157 for processing, testing and issuing (PTI) each blood unit but also loses money because of unsatisfied orders and unsatisfied patients. The NBS revenue is generated by the hospitals which pay the NBS $220 for each delivered blood unit. Any profit made by the NBS goes to R&D which is vital for processing and testing breakthroughs which may have direct medical effects. One must also consider that the budget of the hospital is not unlimited.

In the beginning of the Blood Supply Chain Game there are 100 blood units stock in the NBS Centre bank. There are also 25 units in the large hospital bank (H_L), 15 blood units in the medium's hospital (H_M) and 5 units in the small one (H_S). The game is played for 1 week - 7 days.

The list below presents all the necessary data required for the data record sheet in addition to the two tables above.

Revenue gathered from hospitals

Price = $220 per delivered blood unit

Costs for the NBS

Processing= $157 per unit

Unsatisfied doctor's order = $63 per unit

Unsatisfied patient's transfusion = $785 per unit

Transportation = $47 per hospital

Multi-stop Transportation = $78

Inventory on hand day 1

NBS stock = 100 units

HL stock = 25 units

HM stock = 15 units

HS stock = 5 units

Activities in the order of happening

NBS collections are available as NBS processed units the next day

Daily Hospital orders to NBS = Doctors orders - hospital stock

Orders are placed from hospitals in the following order: H_M, H_S, H_L

a) Hospital places order b) NBS issues to this hospital by subtracting from the NBS stock

Doctors' orders Usage = 65%

The Objective

Following the logic of the game described above, the aim of the player is to make such decisions that maximize the "profit" of the NBS which is highly related with satisfying as many hospital patients as possible and as many hospital orders as possible. The main question that the player has to answer is how much of each hospital's order to satisfy considering its limited stock.

Understanding the Data record sheet

The learner must fill in the data record sheet (Figure 14) starting from week 1 Monday in the following order:

1) row by row
2) day by day
3) sum the NBS profit for all 28 days.

Hints for calculations

- NBS Processing units = daily NBS collections (previous day from Table 1)
- NBS Processing cost = $157 x NBS Processed units
- Doctors' orders to hospital bank = daily Doctors' orders (same day from Table 2)
- Hospital stock = Hospital Stock (previous day) + NBS Issues per hospital (previous day) + Hospital actual Transfused Units (previous day)
- Hospital orders to NBS = Doctors orders to hospital bank (same day) - Hospital Stock (same day)
- NBS stock = NBS Processed units (same day) + NBS stock after H order (previous day)
- NBS issues to H = decision point (try to satisfy hospital orders according to NBS stock)
- NBS Issues SUM = NBS issues to H_M + NBS issues to H_S+ NBS issues to H_L
- NBS Revenue = $220 x NBS Issues SUM
- Unsatisfied orders = Hospital orders to NBS - NBS issues to H
- Unsatisfied orders cost = $63 x Unsatisfied orders SUM
- Hospital available stock after NBS issues = Hospital stock (same day) + NBS issues to H
- Hospital needs for transfusions = 65% x Doctors orders to hospital bank (same day)

- Hospital actual Transfused Units = Hospital needs for transfusions or Hospital available stock after NBS issues (if smaller than needs for transfusion)
- Unsatisfied patients = Hospital needs for transfusions - Hospital actual Transfused Units
- Unsatisfied patients cost = $785 x Unsatisfied patients
- Transportation cost = $47 x Number of NBS issues to H
- NBS profit (for R&D) = NBS Revenue - NBS Processing cost - Unsatisfied orders cost - Unsatisfied patients cost - Transportation cost

Scenarios

The game can be modified to incorporate all 3 (deterministic) policies.

The three policies of Step 2 are now described below in more detail:

- In Policy 1: Assign Stock on Demand, the player is faced with the scenario described above. The only decision that has to make is how much of each hospitals 'order to satisfy in the sequence that these orders arrive to the NBS and make all related calculations.
- In Policy 2: Assign Stock on Demand with adjusted Collections, the player can increase or decrease the NBS collections (supply) by giving a different value (i.e. increasing the NBS collections to 670 blood units and then adjusting the daily collections in accordance to the probabilistic function of Table 1). Once this decision is made then the same logic as in Policy 1 applies.
- In Policy 3: Assign Stock Collectively with adjusted Collections, the NBS-distributor uses a fairer rule to issue units to hospitals and ships units to hospitals collectively utilizing the less expensive multi-stop transportation method of $78 to satisfy deliveries in more than one hospital. However, if only one hospital places an order for a day then this cost is back to $47 round trip. Other than that, the same decisions apply as in Policy 1.

Weeks	Week 1						
Days	M	Tu	W	Thu	F	Sa	Su
NBS Processed units	100						
NBS Processing cost							
Doctors orders to hospital bank							
H_M							
H_S							
H_L							
Hospital stock							
H_M	15						
H_S	5						
H_L	25						
Hospital orders to NBS							
H_M							
H_S							
H_L							
Hospital Orders SUM							
NBS stock							
NBS issues to H_M							
NBS stock after H_M issues							
NBS issues to H_S							
NBS stock after H_S issues							
NBS issues to H_L							
NBS stock after H_L issues							
NBS Issues SUM							
NBS Revenue							
Unsatisfied orders							
H_M							
H_S							
H_L							
SUM							
Unsatisfied orders cost (NBS Penalty)							
Hospital avaliable stock after NBS issues							
H_M							
H_S							
H_L							
Hospital needs for transfusions							
H_M							
H_S							
H_L							
Hospital actual Transfused Units							
H_M							
H_S							
H_L							
Unsatisfied patients							
H_M							
H_S							
H_L							
SUM							
Unsatisfied patients cost (NBS penalty)							
Transportation cost							
NBS profit (for R&D)							
NBS profit SUM							

Figure 14: Data record sheet of the Blood Supply Chain Game