SIMULATION OF A BLOOD NETWORK WITH COLLECTIONS AND DEMAND NORMALIZED TO CANADIAN POPULATION MEANS

By

Neda Hashemi

Submitted in partial fulfilment of the requirements

For the degree of Master of Applied Science

at

Dalhousie University

Halifax, Nova Scotia

July 2016

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Abstract

Red blood cells (RBCs) can be classified into 8 types: 4 blood groups (A, B, O) and an Rh factor (+ or -). When a transfusion is required, the best outcomes are achieved when patients and donors share the same ABO/Rh. However, blood can be transfused from compatible donors to compatible patients; for instance, any patient can be transfused with O- blood. Because blood is also a perishable product, many hospitals, especially small facilities in remote locations, over stock with O type or A type blood. This requires suppliers to collect more of these types than would be expected, especially O- blood.

In this study we adapt a simulation framework of a regional blood network to determine the impact of changing collection and transfusion practices in which blood is collected and used at rates equivalent to the ABO/Rh distribution of the underlying population. The model was developed to represent the blood supply chain in Newfoundland (a small region) and ported to Ottawa (a medium centre) and BC and Yukon (a large centre). The results of the study show that normalizing demand and collections to match the distribution of blood types within the Canadian population would lead to healthier inventory levels for most blood types, at the cost of additional hospital wastage. Results also show that O- shortage and emergency orders increase when collections and demand precisely match the distribution of blood types in the population. Therefore, we undertake an additional set of runs to determine the minimum level of O- over collection necessary to achieve nominal shortages for all blood types.

Our results suggest that if hospitals request blood types at a rate equivalent to their distribution in the underlying population, collections of O- blood can be reduced from 5.8% above the population distribution to 1-2% above the population distribution without creating product shortages. Implementing a collection and ordering policy reflecting the distribution of blood types in the population would, however, increase hospital wastage to between 1.12% and 4.79% of average daily demand.

List of Abbreviations Used

CBS	Canadian Blood Services
FIFO	First-In/First-Out
RBCs	Red Blood Cells
Rh	Rhesus
MDOH	Mean Days On Hand
KPI	Key Performance Indicator

Chapter 1 Introduction

Blood transfusion is a critical element in treatment of individuals with severe blood loss due to surgery, accidents, or infections; there are numerous situations that require blood transfusions, including chronic anemia, cancer treatment, organ transplants, kidney failure and gastrointestinal bleeding. Transfusion science has made it possible to separate each donated whole blood unit into components including red blood cells (RBCs), plasma and blood platelets. Historically, red blood cells account for the largest proportion of products transfused (Prastacos, 1984). RBCs perform the critical function of delivering oxygen to organs and tissues throughout the body. RBCs can be divided into 8 categories – 4 blood groups and an Rh factor, whose distribution varies from population to population. (Wikipedia, 2016.) For an example of comparison of blood type distribution across two countries, see Figure 1.

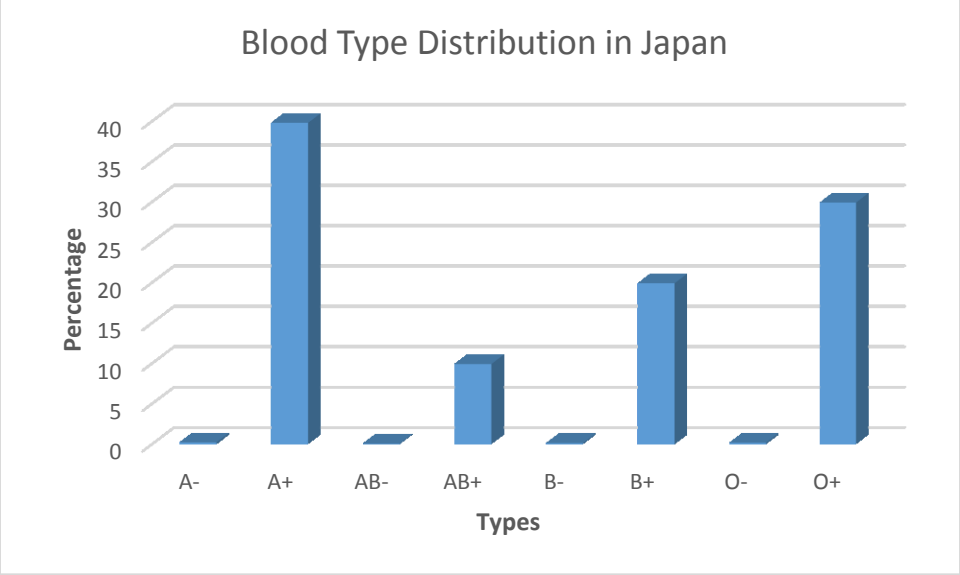

Figure 1- Distribution of ABO and Rh of blood among the Japanese population

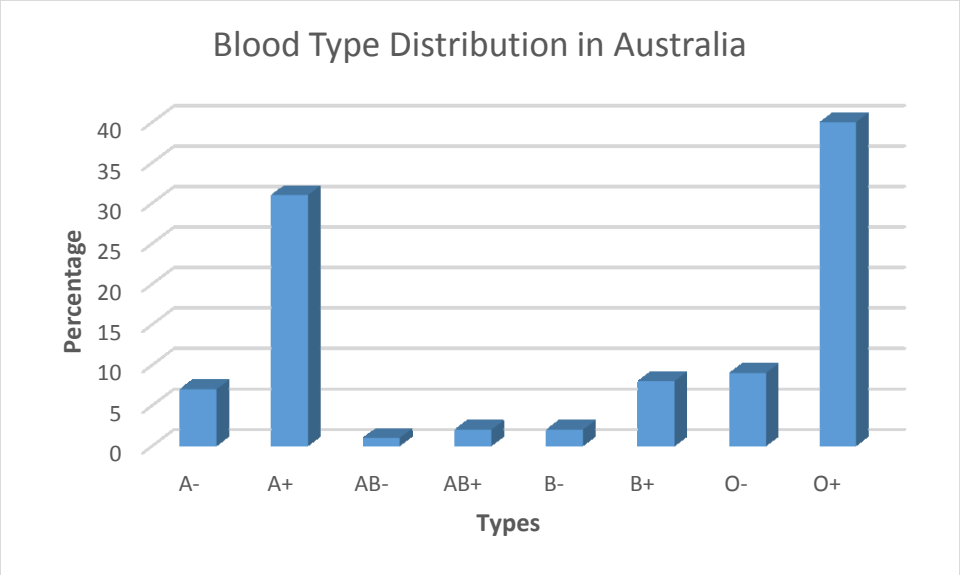

Figure 2- Distribution of ABO and Rh of blood among the Australian population

As can be seen in Figure 1 and Figure 2 , distribution of blood types differs by population. However, A+ and O+ are the most prevalent types, whereas B- and AB- are the least prevalent types, among all populations.

The distribution of blood types varies from 39% (O+) to 0. 5% (AB-) in the Canadian population (Canadian Blood Services, 2016.) The Canadian ABO and Rh distribution is illustrated in Figure 3.

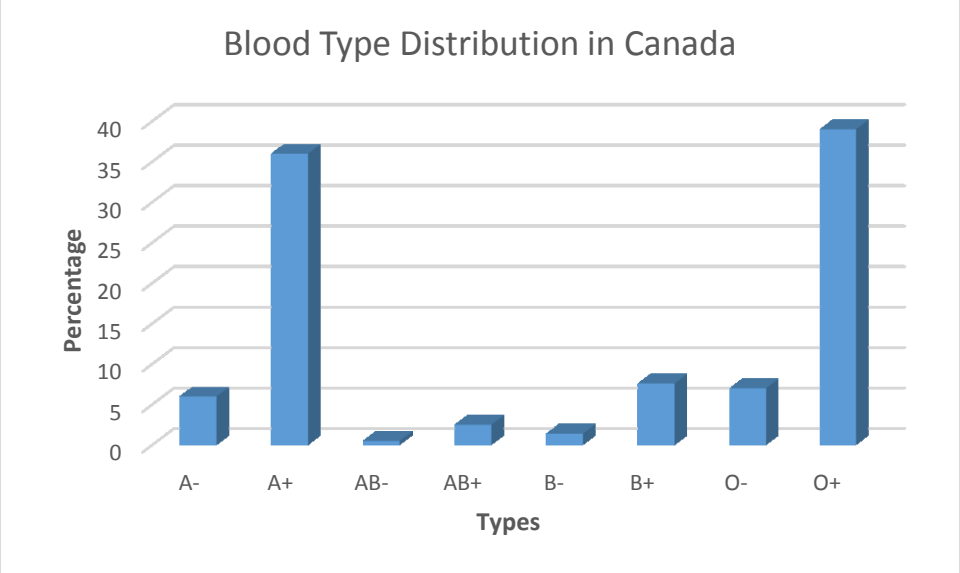

Figure 3- Distribution of ABO and Rh of blood in the Canadian population

Blood belongs to one of four groups, A, O, B, or AB. This categorization depends on the type of antigens present on the surface of RBCs. RBCs that do not have either of A or B antigens are known as group O, the most common ABO group. Another important blood group categorization system is the rhesus (Rh sometimes also called Rh-D) system. More than 4 out of 5 people have the Rh-D antigen on their RBCs and therefore are known as Rh-D positive; the rest are known as Rh-D negative.

Clinically, it is best when patients receive blood product from a donor who has the same blood group and Rhesus factor as the patient. However, it is possible to transfuse blood from compatible donors to compatible patients. For instance, all Rh positive patients can receive transfusions from Rh negative donors. People whose blood is group O and Rh-D negative, therefore, are known as O-. Because their blood has no A, B or Rh-D antigens, it can be given to anyone safely, which is why group O negative donors are known as "universal donors" and their blood is in high demand.

See Table 1 for a list of compatible RBC types; the possibility of substitution of course adds to the complexity of decision making in RBC inventory management.

	Donor's Blood Type								
Patient's Blood Type	Blood Type	O-	O+	B-	B+	A-	A+	AB-	AB+
	AB+	✓	✓	✓	✓	✓	✓	✓	✓
	AB-	✓		✓		✓		✓	
	A+	✓	✓			✓	✓		
	A-	✓				✓			
	B+	✓	✓	✓	✓				
	B-	✓		✓					
	O+	✓	✓						
	O-	✓							

Table 1- Compatibility between blood types

Successful management of RBC inventory is a crucial factor in the efficient and effective delivery of health care, since blood is a naturally scarce resource and has a limited shelf-life. In current practice, the shelf-life for RBCs is 42 days. At present, there are no artificial substitutes for RBCs and therefore donations from volunteer donors remains the sole source for most blood products. Reliance on

voluntary donations, however, makes blood supply uncertain. Furthermore, demand for blood is stochastic. It is suggested that it will become increasingly difficult to obtain an adequate supply of blood due to aging populations, which reduces the pool of eligible donors and also results in a growing need for blood products due to higher demand for these products (Greinacher et al, 2011).

Because blood is both perishable and clinically important, blood inventory management must balance two conflicting objectives: minimizing blood shortages, while promoting effective utilization of blood

The Canadian Blood System

The blood supply in Canada is managed by two independent, not-for-profit organizations, Canadian Blood Services (CBS), and Héma-Québec. Héma-Québec manages the blood supply within the Province of Québec, while Canadian Blood Services is responsible for providing service in all other provinces and the territories. The two organizations combined provide approximately 1.1 million units of RBCs to healthcare facilities across Canada annually. While each organization provides service to a distinctive division of the Canadian population, they share the common goal of delivering an on time, satisfactory, safe and streamlined blood supply to the Canadians.

CBS is responsible for managing all aspects of the blood system outside of Quebec including donor recruitment, testing and universal donor screening, plasma collection, blood product distribution, and supply management of blood product demand from hospitals and clinics across Canada. CBS presently operates 42 collection sites, 3 bloodmobiles, 10 manufacturing sites, and 2 blood testing facilities. In 2011-12, CBS held 22,000 donor clinics, collected over one million units of whole blood from 410,000 donors, and supplied over 460 hospitals and health facilities in 12 provinces and territories with whole blood, plasma, and platelet products. CBS' total expenses, in 2011-12 was estimated at $980 million. Transfusable products, (mainly RBCs), accounted for 48% of CBS' total expenses (CBS, 2013).

Over Ordering of Universal and High Demand Blood Types

Since blood products are perishable, a common practice is to order only common blood types, supplemented with a reserve of universally compatible blood (O-). Since hospitals demand O- blood, blood system suppliers are usually forced to over collect universal blood types, especially O-. While hospitals would like to cover the demand for all types, including less universal types, with exact matches they must also protect against high wastage rates common with less universal types. Therefore, depending on the size of the hospitals and local hospital ordering practices, it is not uncommon for O type blood to be ordered and used at a rate that is 50% greater than the population norm would suggest. This demand for O type blood frequently results in low inventory levels for O type products and subsequently larger costs for recruiting and collecting extra O- units to "catch up" with demand.

However, ordering practices could be modified such that blood of a specific group and type is requested at the same rate at which it appears in the population. Thus, instead of over ordering more universal types, primarily O and A types, hospitals could order less universal types of B and AB at a rate equal to their distribution in the population. Normalizing ordering practices to population means could provide operational advantages. In general, allowing for type matching between blood types enables the usage of rare types in place of O and A type blood. While we might expect to see more outdating blood products as a result of order normalization, we might also expect better product availability and healthier inventory levels for O type. However, switching ordering practices to follow population means could potentially impact the blood supply by reducing the availability of more universal types, especially O-, in a system presently struggling with keeping enough O- on hand, while increasing the amount of wastage of less universal types. As a result, total costs might increase in a system already under pressure by provincial governments to reduce expenses and wastage. Moreover, the new ordering practice could further strain a blood system facing a forthcoming supply problem as a result of an aging population (Greinacher et al, 2011).

Problem Statement

The purpose of this research is to evaluate the impact of an ordering practice normalized to population means, in each of a small, medium and large Canadian regional blood network. To achieve this, a simulation model of regional distribution networks in three Canadian provinces was created. The models were used to test the impact to supplier inventory level, hospital shortage, hospital wastage, and number of emergency orders placed by hospitals, when switching to an ordering practice based, not on historic demand patterns, but on the distribution of blood types within the Canadian population.

Chapter 2 Literature Review

Managing blood inventory at blood banks and hospitals is a complex problem. Among the most important issue that complicates the blood inventory problem is the stochastic nature of blood supply i.e.: supply uncertainty and demand stochasticity. Another matter of concern is the perishability of blood products, which leads to high shortage and wastage costs. Due to the stochastic nature of the blood inventory problem and limited shelf-life of blood products, blood ordering policies must be based on both the amount of stock on hand as well as the age of the stock. Determining the stock on hand for red blood cells is further complicated when the compatibility between the eight blood types is considered. Extraordinary demand for more universal types, especially O type blood, frequently results in low operational inventory levels for O type products and subsequent costs for recruiting and collecting extra units to "catch up" with demand.

When the shelf-life of the product is one period, the perishable inventory problem reduces to the well-known news-vendor problem. However, when the shelf-life of a product is more than one period, addressing the problem becomes more challenging (Blake & Hardy, 2014). A rich body of literature has been developed that deals with exact as well as approximate solutions to address this complicated problem (Telkin, Gurler & Berk, 2001).

Research in blood inventory management dates back to 1960s, with two major periods of contribution: the 1970s and 2000s. (Stanger et al, 2012). Belien and Forcé (2012) review 97 papers relating to blood supply chain issues dating back to the 1960's and note peaks in publications in both the 1970's and 2000's. Much of this literature is specifically oriented towards red blood cell inventory and ordering. Hardy (2015) notes a number of achievements in the area of perishable inventory management, summarizing the early work as follows:

> Pierskalla and Roach (1972) show that for a particular class of perishable inventory problems, including blood inventory, first-in-first-out (FIFO) policy works best. They use dynamic programming, concluding that satisfying demand from the oldest age bucket first, would result in a younger and larger stock on hand and therefore would minimize the amount of inventory necessary to meet future demand. Fries (1975) was one of the first to address an *m* period inventory problem under the assumption of no backordering but, rather assuming emergency orders when there is no stock on hand. He also uses a dynamic programming approach while considering the age of the stock with either a finite or infinite planning horizon. Nahmias (1975) adopts a similar approach to Fries but incurs a cost at the time of wastage to account for perishability of the product. He also indicates that for bigger values of *m* the problem becomes extremely complicated to solve, as it turns into a multidimensional dynamic programming problem. Therefore, in a later article, he proposes approximate solutions instead of exact ones, to address a fixed-life perishable inventory problem (Nahmias, 1978).

Looking at the literature on blood supply chain network planning, we find far fewer papers. This is not surprising, since network planning further complicates an already difficult inventory management problem. Having examined blood inventory management problems at levels of individual hospitals, regional networks and the entire supply chain, Belien and Forcé (2012) conclude that literature focusing on the whole supply chain is minimal, especially before 2000. Nevertheless, in a series of studies from the 1970's, Brodheim and his co-authors describe a number of policies to set inventory levels within a regional blood distribution network. In one of these studies, a regional blood distribution program is set up that applies both statistical analysis and forecasting to ordering and distributing blood. The program is used in a decentralized system in which the centre collects blood, based on historic estimates and each hospital orders according to its daily needs. They conclude that such a system minimizes stock on hand while maximizing inventory utilization (Brodheim & Prastacos, 1979). In another study, Brodheim and his team suggest a procedure that enables blood distribution centres to select target inventory levels and shortage rates based on their mean demand for blood and a selected service levels (Brodheim, Hirsch & Prastacos, 1976). Brodheim et al. also modelled inventory as a Markov chain, with a fixed number of states (Brodheim, Derman & Prastacos, 1975). This model is used to set target

inventories under the assumption of a fixed delivery schedule; they report that by appropriately setting inventory, wastage and cost inefficiencies due to stock over orders can be avoided.

The complexity of blood inventory management problems necessitates methods other than exact solutions to address this genre of problems. Beliën and Forcé (2012) note that simulation is amongst the most common methods for finding normative inventory policies for blood systems, due to its flexibility as well as its potential ability to address "what if" scenarios. One of the earliest simulation studies appearing in the literature is due to Jennings (1973), who uses simulation together with trade-off curves to determine how blood system metrics, including shortage and wastage rates, can be improved. The study was applied both in a single hospital as well as a regional blood network of up to 20 hospitals employing a common inventory policy. Hesse et al. (1997) cluster hospitals with a shared inventory policy and use trade-off curves to analyze simulation results. They apply demand-driven inventory management with periodic review to platelet ordering. Their study results suggest reduced wastage rates, as well as reduced number of units requested on a "stat" basis, could be achieved. Another application of simulation to platelet management, by Sirelson and Brodheim (1991), developed a meta-model, using regression, to find optimal order quantities for a variety of problems. Their results show that with daily scheduled deliveries, following a base-stock replenishment policy, the total number of deliveries can be reduced significantly. Their model allows each hospital and its associated blood centre to select the best stock level as a certain multiple of mean days' demand and to continue to use that stock level as long as there has not been a drastic change in the demand. They also show that, on a regional level, low shortage and wastage rates can be readily obtained; within individual hospitals, low wastage and shortage rates are more difficult to achieve. Another simulation system of a hospital transfusion centre was developed by Rytila and Spens (2006). This system accounts for RBCs, platelets and plasma, and was created to evaluate the blood system in Finland. The metrics considered in the study are outdating costs and percentages, backordering costs and percentages as well as stock

availability and total savings achieved. In total, they evaluate 11 scenarios. One scenario, which aimed at more effective use of rare blood types, assumed blood could only be used by a patient with an identical blood type. Their results suggested a more effective use of rare blood types and enhanced patient safety, but at additional costs.

Yegul (2007) describes the development of a custom model to evaluate inventory policies within a regional blood network. The model was applied to a region of Turkey with two distribution centres and 49 hospital sites to identify policies that reduce shortages, wastage, and order frequencies. He observes that large hospitals do better, in terms of wastage and shortage rates, when compared to small and medium ones. Yegul also notes that the proposed policies work better for Rh positive groups. He compared his studies with those of Katsaliaki and Brailsford (2006) and found that the transfusion centres in his study perform better in terms of wastage and shortage rates.

Another simulation study in the area of platelet inventory management was carried out for seven hospitals by Blake et al. (2010). Their model attempts to find an ordering policy that jointly meets defined bounds on wastage and shortages while minimizing overall number of issued orders over a 7-day planning horizon. Like Yegul (2007) Blake et al. show that finding an ordering policy is easier for larger hospitals, where demand is not only larger but rather uniform i.e. there are not many occurrences of days with zero demand. Fontaine et al. (2009), who also use simulation to study the platelet supply chain in a university based blood system, suggest a collection and testing regime for each day of the week in which collections are explicitly tied to expected demand. They note the importance of agility to respond to sudden changes in demand level, and suggest building stock levels in advance of the beginning of the week when there is more demand, and implementing a better rotation schedule between the supplier and the hospitals, to avoid wastage.

Simonetti et al. (2014) describe a simulation model of the US blood supply chain used to evaluate the outcome of different distribution policies on the amount of daily RBC units available in the system as the age of RBC is decreased from its current shelf life; their model aggregates all the suppliers across the country into one single supplier and all the hospitals into a single hospital. The supplier is assumed to collect blood and distribute it using a first-in-first-out (FIFO) policy. The hospital is assumed to distribute blood FIFO as the baseline policy. However, two non-FIFO policies are also studied against this baseline policy, one of which skews to older units first, the other of which skews to newer units first. Results suggest that the older unit first policy reduces the overall amount of inventory available in the US system by 6-8%, while a newest unit first policy reduces system inventory by 37%. Deviation from FIFO also results in a more serious reduction of on hand stock, when considering individual blood types. For example, O- suffers the most: a loss of 41.5% is observed, when switching to newest unit first policy.

Blake and Hardy (2014) evaluate the impact of a shorter shelf-life for RBC through simulation of the blood network in Quebec. Unlike most models that include only one hospital and one supplier, their model includes multiple suppliers and multiple hospitals. They develop a reusable model to address issues of switching to shorter shelf-life in small, medium and large distribution centres. They notice that increased wastage rates, rather than increased shortage rates, are the primary outcome of reduced shelf-life. Additionally, they show that smaller, more geographically isolated hospitals are less likely to meet the target wastage rates, shortage rates, or target service levels when shelf-life of RBC is reduced from 42 days. They observe that switching to shorter shelf-life across a blood supply chain would not have a uniform effect on all blood types, as some types are more transfusable than other types. Therefore, as shelf-life decreases, universal types, especially O-, suffer the most in response to the additional demand. The impact when switching to newest unit first policy on O- is most evident in smaller hospitals, where less common types are not held. They further conclude that as demand for more compatible types like O- increases, supply centres will face challenges obtaining sufficient

numbers of donations for these types. Therefore, any study addressing the idea of a shorter shelf-life should also assess the capability of the supplier to increase collection of more universal types.

Research efforts dealing with ABO/RH type compatible solutions is limited compared to research that treat RBC as a unified product (Qinglin & Warren, 2014). In general, allowing for type matching between blood types, eases the inventory problem and reduces both shortages and wastage. Type matching also opens up new substitution possibilities that may allow an available unit to fulfill what previously was considered a shortage.

Qinglin and Warren (2014) describe the application of a simulation optimization approach, coupled with a hybrid metaheuristic search algorithm, TA-TS (Threshold accepting and Tabu Search) to a single distribution centre and a single hospital. In this study, three scenarios were examined: no ABO compatible substitution, ABO compatible substitution at hospital only and ABO compatible substitution at both hospital and blood centre. The accelerated use of all blood types, which maximizes their utilization, leads to lower wastage rates. They report a 16% lower wastage rate, when ABO compatibility between the blood types is allowed; however, in the ABO compatible scenarios there is a clear trend of overuse of O types. They also note that as the shelf-life of blood decreases, more O type is needed to substitute for other types. Their research also includes factors such as the ordering size, age and amount of stock available for each blood type, and the potential savings are quantified in terms of each blood type.

Katsaliaki and Brailsford (2007) describe the use of a large scale simulation model to evaluate the function of operational policies across a blood supply chain. They account for compatibility between different blood types when evaluating their policies. They conclude that lower inventory levels could be achieved by applying more efficient cross matching policies. Their study could be applied to larger systems but the extended model should be executed via a distributed simulation environment

(Brailsford, Katsiliaki, Mustafee & Taylor, 2007). They also recommend using their system to identify better practices across different sized hospitals.

The possibility of substitution between blood types, leads to another issue: over ordering of more transfusable types, namely O types. In fact, many hospitals in the CBS supply chain, especially small and medium hospitals, order only A and O types. In the same manner, CBS supply centres generally over collect more universal blood types, especially O-.

There is a limited literature addressing type O over collection. One of the early papers by Freidman, Abbott, and Williams (1982), uses a simulation to explore various blood ordering policies for a hospital. They note the mechanistic and inflexible manner hospitals use to order blood to guard against blood shortages, especially in the times of emergency. They indicate that this fear is more intense in more geographically isolated areas, which is the cause for more unreasonable target inventory levels for group O and non-group O types. They also criticize works done by Brodheim, Hirsch, and Prastacos (1976) on the grounds they establish target levels only after having an "acceptable" shortage rate in mind, rather than employing mathematically established target levels. They suggest a step-by-step hospital blood inventory action plan that focuses on excessive cross-matching reductions as first step. The plan then aims to reduce non-group O inventory by 10% while keeping the target inventory for group O in the same range as before. In the next step, they reduce non-group O by another 10%, plus reducing group O by 10%. They suggest that this lag in the reduction of group O target inventories, which leads to partial protection of these types, would not lead to unacceptable shortage rates across the system. It is concluded that implementing this action plan, when paired with extending the shelf-life of blood, would result in considerable reduction of wastage rates (i.e. below 1%).

Page et al. (2014) describe a statistical analysis to identify whether there is a significant relationship between the number of O- units held by a blood bank and the number of fridges holding

these units, especially in remote areas. Their study finds that the number of O- units issued increases with a rise in the number of fridges, but cannot conclude if this increase was according to guidelines or not. In other words, they are uncertain whether this increase was due to immediate need for O- stock or because of easy access to more units of the most transfusable type and failure by staff to evaluate if there is enough time to obtain group-specific cells. Page et al. also conclude that a higher percentage of issue of O- is not correlated with a higher wastage of O-, as there might be other policies in place that prevent wastage of O- type. However, they note a significantly lower wastage in O- units, when emergency stock is rotated between hospitals for general use. They suggest that, considering the financial pressures to move towards a more consolidated model with fewer remote transfusion laboratories (fridges), the O- stock of each individual fridge be assessed to determine if there is a real need for these in transfusion laboratories. They also propose that the substitution of O+ stock for O- stock in Rh-D positive patients might have little or no effect on loss of safety but would result in a healthier level of O- supply. Of course, some number of O- units must always be kept at hand to transfuse to patients when there is an emergency need and not enough time to determine a patient's blood group and type.

Thus, we conclude that while there is substantial literature on RBC inventory problems, it is largely focused on single sites, such as a hospital or a distribution centre. Moreover, there are few sources that account for the possibility of compatibility between the eight blood types; existing papers in the literature generally fail to address O type over ordering that is customary in hospitals to protect against wastage. There is no study, which we are aware of, that addresses how the blood system could change if blood was required at the same rate as it appears in the population.

In this research we modify ordering practices such that blood of a specific group and type is requested at a rate equal to that in the Canadian population. We develop a simulation model for

evaluating blood product supply chain metrics within a broad geographically distributed regional network comprising of a distribution site and a set of customer hospitals.

Chapter 3 Methodology

Model Description

We employ a discrete event simulation method, developed in Microsoft Visual Basic.Net to evaluate blood ordering policies in each of a small, medium and large volume Canadian Blood Services regional blood centre and the hospitals within their catchment areas. The simulation framework employed in this study is based on a simulation framework developed by Blake and Hardy (2014) initially to study the effect of shorter shelf-life in a Hema-Quebec distribution centre.

The framework was designed to create reusable models that could be applied to answer a range of research questions related to inventory and logistics policies. This study employs an instance of the reusable framework to study the effect of a new ordering policy on a regional CBS supply chain. In this new ordering policy, the data has been modified such that the distribution of blood types in collection, imports, demand and exports are equivalent to that of the Canadian population.

Adapting the model developed by Blake and Hardy (2014), a blood supply chain was built that also includes two Microsoft Access databases: a transaction database and the application database. The transaction database stores historic data of a CBS collection/distribution centre, detailing the progress of a single blood unit from collection to disposition; it is used to develop input distributions for the simulation. The application database records output from the simulation and contains simulation execution parameters, such as length of runs and number of replications.

The simulation framework is built on a paradigm in which it is assumed that there is a single distribution centre that collects red blood cells, tests, and distributes them to a set of hospitals within its catchment area. All the hospitals in each region receive RBCs from the supplier in their area. This supplier in turn exists within a network of other suppliers that can either import or export units to each

other. Hospitals are assumed to manage their own local supply of RBC and dictate local inventory and ordering behavior. Hospitals also have routines to simulate patient demand for blood. Hence, the model simulates an end-to-end supply chain.

The producer and the hospitals are modelled as separate object classes, namely the "Supplier" and the "Hospital" classes. Each object has a series of properties that define the state of the object at any given time, and a series of methods that change or update the system's state. At the beginning of each run, the system is initialized: Model control parameters are read in from the application database and system data is read in from the transaction database. Supplier and hospital objects are instantiated and object properties are set according to data read in from the transaction database. The daily routine is then executed. At the end of each replication, a statistics collection routine is executed to summarize the daily simulation results. When all replications are complete, a final collection routine is executed to summarize results across all replications and to output the results to the application summary database.

To better understand the study framework, an overview of the real-world CBS blood supply chain is presented. Later an overview of the reusable framework is provided. The overview includes a description of the transaction and the application database, as well as the supplier and hospital objects. The verification and validation of the framework against a small centre and later a medium and large centre is then presented. Finally, we explain how an instance of the reusable model has been applied to study a new ordering policy, based on distribution of blood types within the Canadian population, in a small regional CBS supply chain and later a medium and large CBS regional supply chain that include a collection/distribution centre and the hospitals they serve.

CBS Supply Chain Overview

Canadian Blood Services (CBS) is the agency responsible for managing the blood supply in Canada outside of Quebec. CBS collects whole blood from Canadians. It tests, produces and distributes blood

products derived from Canadian donors and provides these products to authorized health care facilities. As a pan-Canadian biological manufacturer and clinical services provider, CBS uses many operational resources to deliver products and services effectively and efficiently. CBS schedules more than 16,000 clinic events annually through various permanent and mobile collection sites. They also operate two blood testing facilities and nine manufacturing facilities to deliver their products and services (Canadian Blood Services, 2015). In addition to managing the whole blood derived supply chain, Canadian Blood Services is the sole purchaser and distributor of fractionated plasma products in Canada. These products, which are used to treat diverse genetic and blood related disorders such as sickle-cell anemia, are sourced from the international marketplace, purchased by CBS, and provided to Canadian hospitals.

Canadian Blood Services, which was first formed in 1997, succeeded the Canadian Red Cross as Canada's blood agency outside of Quebec. Since its formation, CBS has broadened its product lineup and is now responsible for also managing the Canadian unrelated bone marrow transplant registry, managing Canada's public cord blood bank, and maintaining registries of individuals requiring solid organ transplants. The focus of this research work, however, is the whole blood supply chain.

Canadian Blood Services is a federally regulated agency, falling under the auspices of Health Canada. While federally regulated, CBS is paid for by provincial and territorial ministries of health. The provinces each pay a share of the overall cost of products and services provided by CBS based on the fraction of the products shipped to that province or territory, as compared to the Canadian total. This funding mechanism is simple and straightforward to apply and it provides provinces and hospitals an incentive to be cognizant of waste. However, as we note, the emphasis on minimizing RBC wastage can also result in a distortion of ordering behavior at hospitals as we will describe in this thesis.

Each CBS regional supply chain consists of a supplier that is responsible for collecting and distributing blood to a set of hospitals in its catchment area. The supplier collects blood on a daily basis, based on a target collection volume which is determined several months in advance. Operationally, the

collections are somewhat adjustable to current inventory on hand, which fluctuates in response to external factors such as the anticipated outbreak of pandemic flu or public holidays. The distribution of blood type collections is stochastic, as the center has only marginal control over the type of donated blood. A national call centre is used to contact donors ahead of specific collection events. Donors are contacted through various mediums (phone, web contact, email) to secure commitment to book and keep blood donation appointments. The call centre can influence, to a limited degree, the number of donors attending a clinic and is able to preferentially contact donors having a specific blood type. In general, the recruiting system attempts to influence donor volumes through various mediums when inventory is not within a target range and thus will expend extra effort to recruit donors of a particular type to maintain inventory level when stocks are low. As a result, since more universal blood types are disproportionately requested, A and O types are generally over recruited and over collected across the entire blood supply chain. In some centres, O- blood is collected at a rate that is 50% more than its prevalence in the Canadian population. Demand for O- blood is driven by both clinical requirements and an economic pressure to avoid wastage.

After collection, the raw blood is tested for transmittable diseases at one of two national testing laboratories, located in Toronto and Calgary. Whole blood is manufactured at one of 9 regional production centres to produce a range of products, including red cells, plasma, platelets, and cryoprecipitate. In general, production and testing for RBC units takes 1-2 days. Thus, units that are collected on a particular day are tested on the day after and then end-labelled, and made available for distribution to hospitals on the morning of the second day.

Hospitals place orders with the supplier according to a (s, S) policy, where S is the order up to inventory quantity and s is the inventory level order trigger point (Blake &Hardy, 2014.) Hospitals set their (s, S) for each blood type based on experience. S values are set individually for each blood type in

each hospital and s values are set individually for each blood type in each hospital in the following manner:

> s = S – (mean daily demand for the blood type * the mean number of days observed between orders)

For a complete list of (s,S) for each hospital and each blood type see Appendix C.

The hospitals observe their inventory and issue their orders late in the day. These orders are received by the supplier and are filled and dispatched to the ordering hospital overnight, so that they are available early next morning before the peak of demand. Hospital orders are assumed to be processed as a batch. In our simulation we assume the supplier fills hospital orders starting with the hospital with the oldest historic average age at distribution and proceeding to the hospital with the youngest historic average age at distribution. As stock is generally distributed to hospitals in a FIFO manner (with some few exceptions), this assumption results in slightly older blood being distributed to larger hospitals with more demand and with younger blood going to smaller ones; this is consistent with the supplier's policy in real world that attempts to ensure hospitals with small demand receive younger blood.

Demand is experienced by hospitals throughout the day. Demand is filled from inventory on hand using a FIFO ordering policy. A hospital first tries to fill demand with an exact match. If there is no exact match on hand, the hospital fills demand with a compatible match (In our simulation, we assume that hospitals first try to fill demand with less universal types and then more universal types, in such a way that filling demand from O- is the last resort). However, if no compatible match is on hand, the hospital issues an emergency order to the supplier. At the supplier side, the same procedure happens. The emergency order is first filled with an identical type and if no identical match exists, then with a compatible type. If no compatible unit exists to satisfy the demand, the demand item is counted as a shortage. Before the day ends, the supplier may export units to other suppliers.

Hospitals are not charged for the RBC units they order, but because provincial shares of the CBS budget are dictated by the volume of product ordered, there is pressure from provincial and territorial ministries of health to contain costs by minimizing product wastage. Therefore, to guard against high amounts of wastage, hospitals have a tendency to over order high demand and universal types and to rely on A and O to fill the demand for the non-universal types through compatible matching. This is particularly true at hospitals that are geographically isolated or that provide a limited number of transfusions per year.

Transaction Database

Data for the modelling framework was derived from transaction level records extracted from Canadian Blood Services' production database. The database includes information regarding all RBC units collected, distributed, or disposed of at any site in Canada between the periods of 01 April 2011 and 31 March 2012. In total, the data included slightly more than 1.3 million records. Each record tracks the journey of one unit through the supplier's portion of the supply chain: collection date, release date, expiry date, disposition date, and disposition status**.** Since there is also an arrangement between the supply centres across the country to transfer units between themselves, a list of unit transfers for the period between 01 April 2011 and 31 March 2012 was also obtained.

To prepare the data for use in the simulation models, Blake and Hardy (2014) wrote a series of queries in MS-Access. The queries perform three main functions – separating the data into region specific databases, formatting the data for use in the simulation models and building input distributions, and summarizing the data for verification and validation purposes. The process of attaining tables from the transaction and transfer databases, is represented in Figure 4.

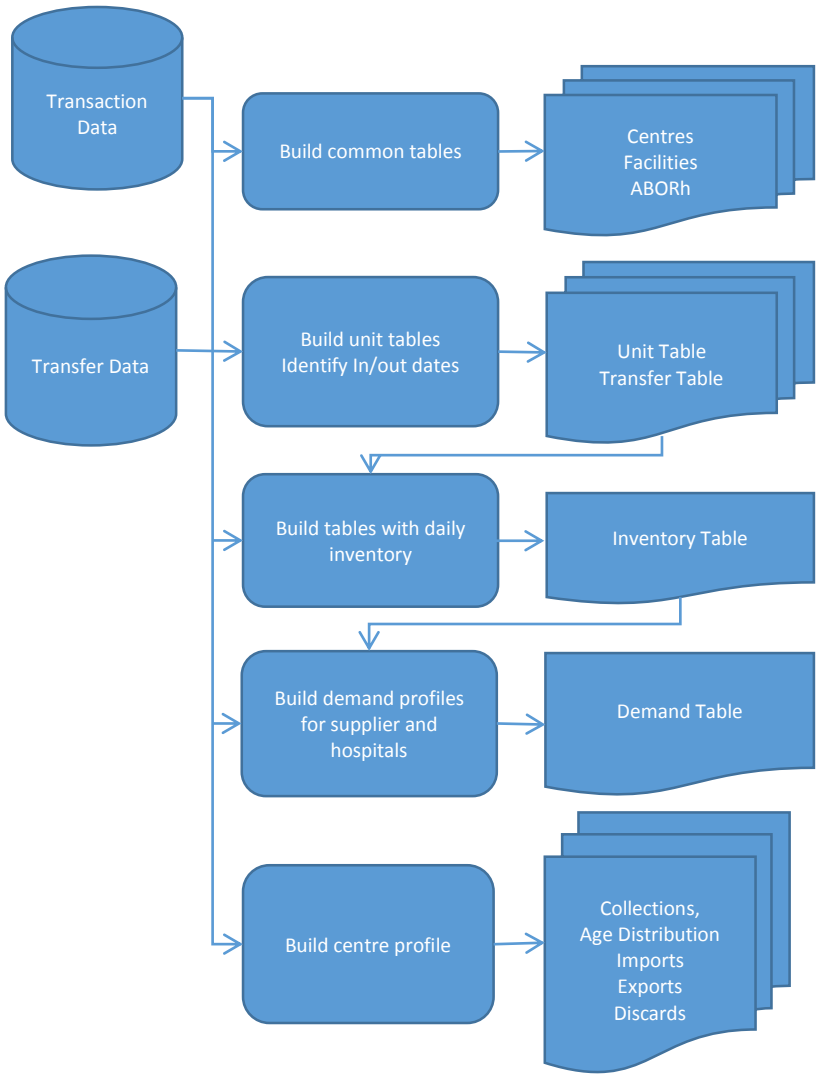

Figure 4- Schematic representation of transaction level database and queries required to prepare data tables for the simulation framework (Blake & Hardy, 2014)

As can be seen in Figure 4, to prepare data for the simulation model, the raw data from the transaction data base, and transfer data between suppliers across the country are combined. After combining the raw data from these two databases, common tables defining centres, hospitals and ABO/Rh are built. In the next step, the unit table and transfer tables are created; the former stores the key data of entrance and exit dates of all units and the latter provides a complete profile on units transferred between centres. The inventory table, which stores the inventory status by date and type, is built next. Once inventory tables are complete demand tables for both day of week and ABO/Rh are

built. Finally, the centre profile, including the collection and imported units by day and type, together with their age distribution, as well as exports and wasted units, is built.

At the beginning of each run, model inputs such as number of units collected, broken down by ABO and Rh, day of week, number of units demanded for each hospital by either ABO/Rh or day of week, as well as the number of units imported or exported by either ABO/Rh or day of week, are read in from the transaction database.

Application Database

The application database stores simulation control parameters for the model framework as well as user specifiable model parameters. It also serves as a repository for output information from the simulation model. Simulation control parameters include the length of runs, number of replications, and warm-up period. User-specifiable parameters determine whether or not substitution for compatibility between blood types is permitted during a model run, whether or not to collect blood based on population distribution, and the maximum shelf-life of RBC in the model. In instances where the framework is used to execute a series of experiments, the application database also stores the experimental control parameters. When model runs are complete, results are output to the application database for review.

Simulation Framework

The simulation framework assumes there is a single distribution centre that collects red blood cells, tests and distributes them to a set of hospitals in its catchment area. Hospitals in the framework order units and fill patient demand. While the simulation framework includes about a dozen objects that perform functions ranging from user interface to statistics collation, most model logic, including daily

supply chain activities, is encapsulated in the supplier and hospital objects, which we briefly describe below.

The Supplier Object

The "Supplier" object represents the blood producer in the model. It is assumed that there is only one supplier in each region. Therefore, all hospitals in the region receive products from the sole regional supplier. The supplier object has a number of properties that are either informational in nature, define parameters used by the simulation to update the state of on hand inventory, bring in new inventory from collections, import units from or export units to another region, and fill hospital orders (Blake & Hardy, 2014).

For a complete list of methods in the supplier object see Appendix A.

A list of the key methods for the supplier object is provided below. The methods are listed according to the daily routine of the simulation cycle.

AdvanceInventory: Causes stock at hand at the supplier to age by one day, at the beginning of each day. Stock with remaining shelf-life of -1 day is outdated and counted as wastage.

ArriveInventory: This method represents blood collections; hence, it causes units to arrive at the supplier site from testing. The supplier collects blood on a daily basis based on a target collection volume that is determined several months in advance, but which can be modestly adjusted according to the current inventory on hand. In the model, the number of units collected on a particular day is sampled from a Poisson distributed, day of week specific value. Once the total collection value has been determined for a particular day, each unit is assigned a blood type (ABO and Rh status), using an empirical distribution, based on the regional supply centre's historic dataset. Also we assume in the simulation model that the age of blood is drawn from a day of week specific empirical distribution that is read in from the historic dataset. To represent the adjustments made by managers in response to fluctuations in inventory level and also due to exogenous events, it is assumed a set of control bands for collections in the simulation. The target inventory level is averaged over the past 7 days for all blood types. When the total number of units on hand deviates from this recorded target inventory, an effort is made to maintain target inventory levels. Collections are adjusted according to the inverse ratio of the inventory level to the target inventory. The level of adjustment to collections is subject to a cap of +/- 20%, per day, to prevent unreasonable swings in collection levels. For example, if on a particular day, the moving average of sum of simulation inventory for all blood types, over the past 7 days, is 450 units, it is determined that the inventory is below the Newfoundland centre historic target inventory and therefore is low. As historic target inventory in the Newfoundland

centre is 505 units, the upper limit is 505*1.1= 555.5 and the lower limit is 505*0.9=454.5. Therefore, collections are raised by the minimum of target inventory/inventory level: 505/450= 1.12 and the adjustment cap (1.2 per day). As a result, weekday Poisson mean for that day will be raised by 1.12.

Import and Export: Import causes units to be imported from other supplier sites. Export causes units to be withdrawn from the supplier site and sent out of the model. Similar to collected units, the number of both imports and exports are drawn from day of week specific Poisson distributions. The ABO and Rh of both imported and exported units are drawn from empirical distributions in the historic dataset. The imported units are assigned a shelf-life based on the arrival age of historic imports.

FillOrder: Calculates the total order for units of each blood type from all hospitals and determines if there is sufficient inventory to fill all hospital order. If there is sufficient stock on hand to meet all requests, no action is taken. If stock at the supplier is insufficient to meet all hospital requests, the supplier will scale hospital demand (units available / units requested) so that all requesting sites receive at least part of their requested amount.

EmergencyOrder: Causes units to be withdrawn from inventory under emergency conditions. For a more detailed description of this method, refer to GenerateDemand at the hospital object.

InitalizeInventory: Causes the inventory at the supplier to be initialized at the start of the simulation run. At the beginning of each replication, it is assumed that the sum of target level (S) of all hospitals is allocated to the supplier each having a randomly assigned age. Thus, the system does not start empty and the supplier is able to fill hospital orders starting on day one.

ClearStatus: Clears statistical counters at the end of each day.

The Hospital Object

The "Hospital" object represents hospitals in the simulation and is similar in concept to the supplier object. The hospital object encapsulates properties that update the state of the hospital's inventory, place orders for and receive new units from the supplier, and generate and fill demand (Blake &Hardy, 2014).

For a complete list of methods in the hospital object see Appendix B.

Below a list of the key methods for the hospital object is provided. The methods are listed according to the daily routine of the simulation cycle.

AdvanceInventory: In a similar manner to the supplier, this method causes stock on hand to age by one day at the hospital site. Stock with a remaining shelf-life of -1 day is outdated and counted as wastage.

OrderInventory: Causes a request for inventory replenishment to be issued to the supplier. At the hospital, inventory is reviewed daily and if below a target level, an order is issued to the supplier to return the inventory to a target level, S (where S>s). If any blood group needs replenishment, the hospital issues an order to bring all blood groups up to their target levels, S, even if the observed inventory is greater or equal to s. This assumption is taken to minimize shipping costs.
Hospital orders are assumed to be placed with the supplier at the beginning of each day before demand is observed.

ReceiveInventory: Causes units to be withdrawn from the supplier. The process of filling hospital orders by the supplier as well as dispatching and transferring these orders, takes place without a delay. However, as the orders are issued by hospitals at the end of the day and then dispatched by the supplier overnight and therefore are ready for delivery in the morning before the peak of demand, the assumption of instantaneous delivery, although deviating from reality, is not completely unrealistic. The method Calls TransferInventory. It is assumed that orders are generally filled First-In, First-Out (FIFO) from inventory on hand at the supplier, starting with the stock with the least remaining shelf-life. However, since FIFO violations occur in practice for a variety of reasons, the model incorporates an additional assumption to address it. This method uses FillOrder to determine if there is enough stock at hand to cover either all or partial hospital aggregate order.
TransferInventory: Causes units to be transferred to the hospital. Inventory is transferred between the supplier and the hospital by decrementing the inventory count at the supplier and incrementing it at the hospital site.

GenerateDemand: Causes demand for product to be generated. Since we do not have actual demand data, order rates from the supplier are used as a proxy for demand data. The method generates a number of requests for blood, using a Poisson distribution with age-of-week specific mean value. Blood group and type are assigned to the demand items via empirical distributions. It is also assumed that demand is generally filled FIFO from inventory on hand at each hospital. If there are no units of a particular type on hand, hospitals will substitute compatible products, where possible. Compatibility matching is done with a set priority, in a way that demand is first filled from non-universal types and then more transfuasable types; using O- to fill demand from other types is the last resort. For example If there is no exact match available to fill demand for B+, the demand is initially filled from B-, then O+ and finally in the absence of these two, from O-. Where no compatible unit exists to satisfy demand, an emergency order is placed with the supplier to fill the demand. If an exact match or compatible unit is available at the supplier, it will be dispatched to the requesting hospital and counted as an emergency order. However, if no exact match or compatible unit is available at the supplier, the demand item is counted as a shortage.

ClearStatus: Causes statistical counters to be cleared at the end of each day.
The daily simulation routine incorporating the list of key methods, is shown in Figure 5.

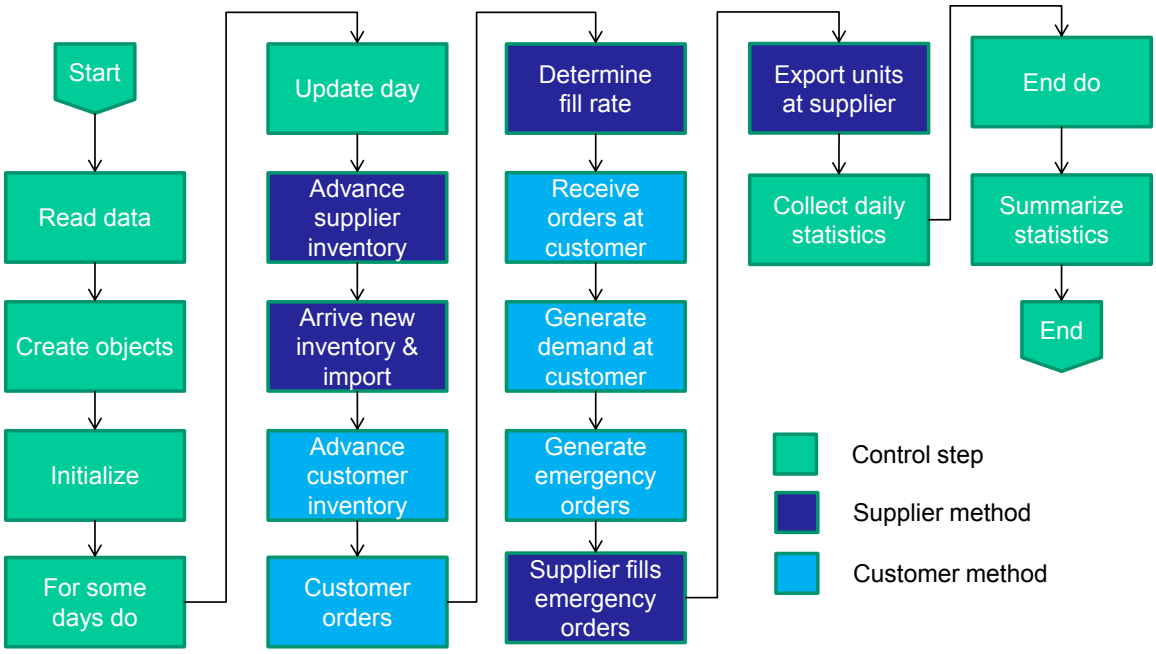

Figure 5- Simulation framework flow diagram (Bake &Hardy, 2014)

For a comprehensive description of daily procedures as observed in real life as well as a description of the complete reusable model simulation cycle, see (Blake &Hardy, 2014) or Appendix D.

Simulation Cycle[1]

At the beginning of each run the system is initialized: model control parameters are read in from the application database and system data is read in from the transaction database. Supplier and hospital objects are instantiated and object properties are set according to the data read in from the transaction database.

Initialization is completed by assigning a starting inventory, by blood group and type, each with a randomly assigned age to the supplier. Once initialization is complete, the simulation is run for a 42-day warm up period before statistics are collected.

[1] The description for the simulation cycle is derived from (Blake &Hardy, 2014)

The model is run for some replications of a specified number of days. On each simulated day, the model executes a sequence of calls to the supplier and hospital objects.

The simulation follows a series of repeating daily cycles at the beginning of each day, which starts by aging stock at both the supplier and hospitals by one day and outdating any unit with a remaining shelf life of -1 days. After aging units, both the supplier and the hospitals observe their inventories. The supplier places an order for the total number of units to be collected. The collection is based on a target volume determined several months in advance, but adjustable to the current level of inventory for all types. The type of the collected blood is then assigned, based on the historic collection data of the regional supply centre. The received units are also assigned a remaining shelf-life drawn from empirical distributions, based on historic data. After receiving units from its own collection process, the supplier may also import additional units from other suppliers based on historic imports. These imported units are also assigned an age from empirical distributions, based on historic data.

Once all incoming inventory is in place at the supplier, the simulation loops through each of the hospital objects and makes a call to advance the inventory. As was the case for the supplier, advancing the inventory at the hospital causes the stock on hand to age by one day. Any units with -1 days of shelf-life remaining are counted as wastage and exit the system. Each hospital object then determines if an order is required. These orders are placed with supplier at the beginning of each day before demand is observed, based on the (s, S) policy. When hospital demand has been determined (and scaled), if necessary, each of the hospital objects is called to receive inventory from the supplier and enter it into their own inventory. Inventory is then transferred between the supplier and the hospital by decrementing the inventory count at the supplier and incrementing it at the hospital site.

Demand for the day is then experienced. To simulate demand for product, a call is made to each hospital object. The call generates a number of requests for blood, using a Poisson distribution with age-of-week specific mean value. Blood group and type are assigned to the demand items via empirical

distributions. Hospitals fill orders first with matching types, then compatible types, and, if no matching or compatible units exist, emergency orders are issued to the supplier. The supplier also checks first for exact matches and then for compatible types. If either exact matches or compatible units are available, they will be dispatched to the hospital and the demand item is considered an emergency order that has been filled. However, if no exact match or compatible unit is available at the supplier, the demand item is counted as a shortage and is disposed. Once all the demand is met, the supplier may export units to other suppliers based on historic exports.

The simulated day then ends, statistics are collected for the system metrics, statistical counters are reset and the daily cycle repeats. At the end of each replication, a statistics collection routine is executed to summarize the daily simulation results. When all replications are complete, a final collection routine is executed to summarize results across all replications and to output the results to the application summary database.

Model Validation

To test the validity of the model against the dataset, a metric which is not input to the model, centre inventory, but is rather derived from its function, was compared against historic results. Validation of a simulated system against a real-world system is only meaningful if the model has reached a steady state, which means the average value of a metric does not change over time. An assumption that model and the system under study are independent and identically distributed, is required. However, the historic data shows clearly that inventory levels within regional blood centres are influenced by exogenous events and thus do not reach a steady state (Blake &Hardy, 2014). Therefore, without a control policy, a simulation model's representation of inventory levels may either grow well beyond those of the real world system, or deplete, resulting in shortages if the model is run for a long period of time (Blake &Hardy, 2014). For example, in Figure 6, we show the real and simulated inventory for Newfoundland and Labrador. In this example, the simulation model is run for one year (364 days),

with a 42-day warm-up period and import/export numbers that mirror real-world data. In initial runs, no control policy was applied to adjust the inventory state. The historic inventory levels are averaged for the period between 01 April 2011 and 31 March 2012.

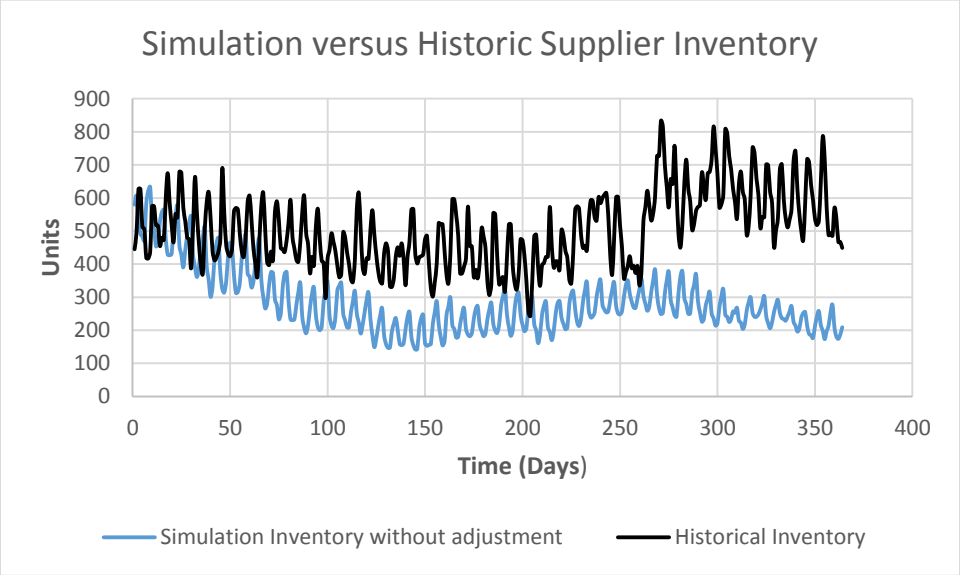

Figure 6- The Simulated inventory level for the Newfoundland centre, in aggregate, without an inventory control policy versus historic inventory

As can be seen in Figure 6 , without a control policy the inventory levels gradually deplete over the course of a year. Based on this analysis, it may be concluded that collections are not independent of inventory state and thus there must be a control policy to adjust inventory levels in response to exogenous events or to instances where inventory positions rose or fell organically over the course of a year. In practice, blood suppliers use a variety of tools to maintain the blood supply. Therefore, extra assumptions are required to ensure the simulated model matches the real world data. To make sure the centre inventory level matched the actual system inventory on hand, a control policy was incorporated into the simulation.

The control policy used in the process of validation in this study is the same that was adopted by Blake and Hardy (2014) in the development of their reusable model. In this policy, collections are modestly increased during periods of shortage and modestly decreased during periods of surplus based

on the comparison of a seven-day moving average of inventory on hand at the supplier against a historic target inventory. This transforms the collections process from a pure stochastic process into a feedback-control system. Under this policy, collections are monitored and adjusted based on an error signal triggered by the difference between target inventory and historic inventory of the last seven days. If the current inventory on hand at the supplier is within 10 percent of target, the inventory on hand is not adjusted. However, if inventory error exceeds the 10 percent boundary, the day of week specific Poisson averages are increased or decreased, based on the seven day moving average, by a maximum limit of 20 percent, per day. For a comparison of simulation inventory level with and without applying a control policy and historic inventory, in the Newfoundland and Labrador centre, see Figure 7.

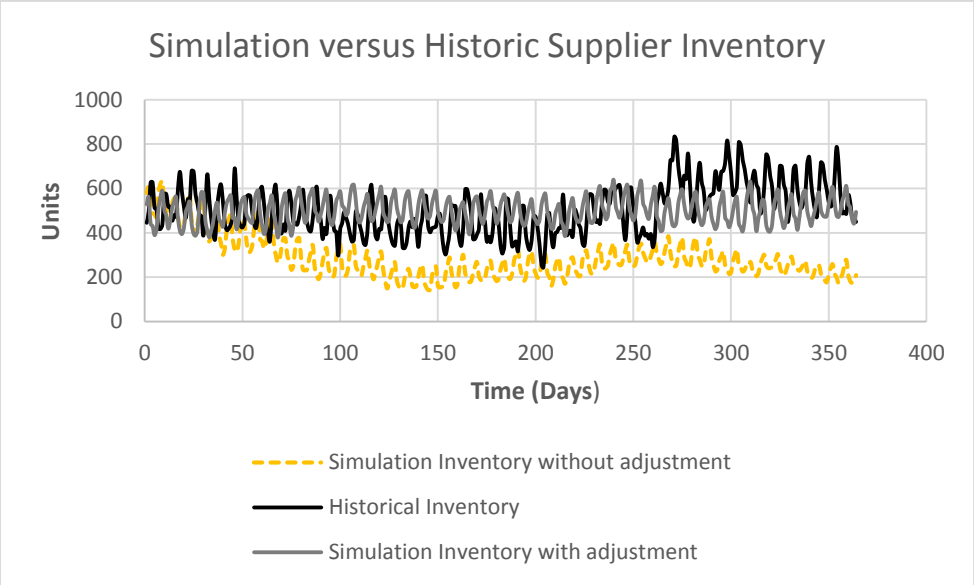

Figure 7- The simulated inventory level for the Newfoundland centre, in aggregate, with and without an inventory control policy versus historic inventory

Another challenging aspect of modelling the blood supply, is the occurrences of FIFO violations in the distribution of blood. FIFO violations occur for a variety of reasons including specific requests from hospitals for fresh blood, as well as a supplier practice of holding units from donors with rare phenotypes in reserve. Another key reason behind FIFO violations is the high inventory level of less universal types like AB+ and B+ which are over collected for purposes other than obtaining RBC units.

To test the validity of the model against the dataset, the age of the stock distributed from the supplier to the hospitals, is compared against historic results. Like supplier inventory, the age metric is not an input to the model, but is derived from its function. When there is too much stock on hand, the supplier might allow older units to outdate and thus ship younger units to the hospitals. In practice, the supplier might not give out stock older than a certain age. For example, it is common practice to not distribute AB+ and B+ units that are older than 15 days until expiry to hospitals. To account for this practice with respect to AB+ and B+, it is assumed in the model that there is a certain threshold for the age of the distributed stock, below which, the supplier would not issue blood. To find realistic thresholds for AB+ and B+, the model was run for 30 replications of 364 days with a warm-up period of 42 days, under a number of different conditions. Each time, the age threshold, below which, stock is not distributed from the supplier to hospitals, is changed, while the average age of the stock distributed from the supplier to the hospitals is recorded. These experiments were repeated until such time as the age of outgoing stock at the supplier reported by the simulation matched the historic data. After running standard statistical tests on the average age metric, the threshold for AB+ was set at 15 days until expiry, and the threshold for B+ was set to 21 days until expiry. For all the other types, we assume that the stock is distributed to the hospitals in a FIFO manner.

Furthermore, the historic data at Newfoundland shows a number of instances where the net number of units collected over the course of the year does not equal the net number of units exiting the system. For instance, A+ and A-, both of which have a large demand in 2011/2012, but the centre did not bring in sufficient units either in the form of collections or as imports to match demand. In the historic data, of course, this implies that the net amount of A+ and A- inventory declined over the course of the year. As a result, when the simulation is run using the historic dataset, it generally holds less inventory than the real world system and correspondingly reports a younger age at distribution in our model, in comparison with historic age at distribution. To show the inventory decrease for A-, the

simulation model was run for 5 replications of 366 days (to be consistent with historic dataset) with a 42-day warm-up period and import/export numbers that mirror real-world data. The historic inventory levels are averaged between the periods of 01 April 2011 and 31 March 2012. The simulation A- inventory state, in the Newfoundland and Labrador centre, is illustrated in Figure 8.

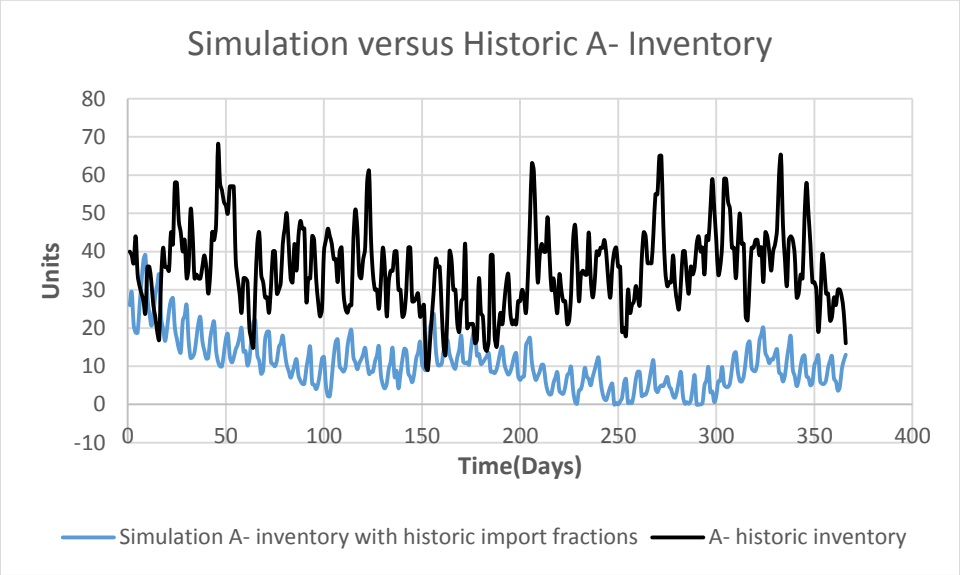

Figure 8- The simulated A- inventory level for the Newfoundland centre with historic import fractions versus historic A- inventory

The net loss in A- and A+ inventory over the course of the historic data creates a problem for the simulation model, since the simulation model cannot come to steady state if it simply reflects the actual input/output process from 2011/12 at Newfoundland. To see the net loss/gain in the Newfoundland historic data, see Table 2.

Type	Starting Inventory	Collections and Imports	Demand and Exports	Wastage	Calculated Ending Inventory	Net Change
A-	40	1697	1705	18	14	-26
A+	141	5390	5406	23	102	-39
AB-	5	91	69	25	2	-3
AB+	36	391	109	274	44	8
B-	12	249	253	4	4	-8
B+	70	1155	736	396	93	23

Type	Starting Inventory	Collections and Imports	Demand and Exports	Wastage	Calculated Ending Inventory	Net Change
O-	46	3032	3032	15	31	-15
O+	95	6962	6972	20	65	-30

Table 2- The net change over the course of 2011-2012 in annual supplier inventory, by type in Newfoundland historic data

Accordingly, in the simulation model an adjustment is made to imports (or exports as the case may be) to ensure that the total net inflow of units into the simulation is balanced with the total net output from the simulation.

The A- inventory with historic and modified import/export fractions is illustrated in Figure 9. After modifying the import fractions, and running standard statistical tests on the average age at distribution for A-, there is no reason to assume that the average age at distribution for A-, observed in simulation, is different from the average age for this type, in historic data set.

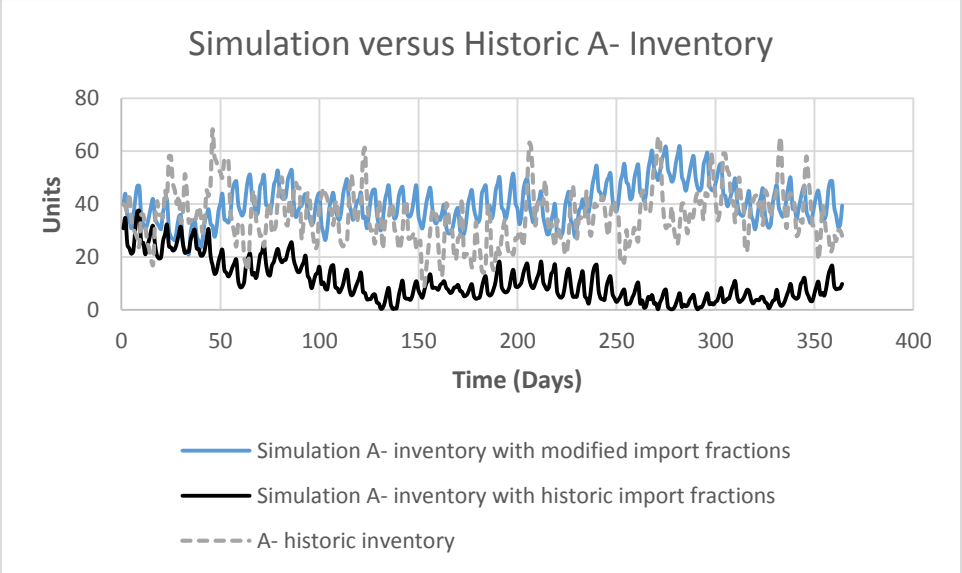

Figure 9- The simulated A- inventory level for the Newfoundland centre with historic and modified import fractions versus historic A- inventory

The validation process demonstrated two important aspects of a blood supply system. Firstly, the blood supply is not well modelled as a pure queue and therefore a control policy needs to be applied to any model representing a blood supply chain. This observation was also noted by Blake and Hardy

(2014). A control policy allows the model to be responsive to random fluctuations and allows it to keep inventory at a steady state. In practice, blood suppliers use a variety of tools to adjust inventory levels, such as encouraging donations when there is a shortage of blood. Secondly, the validation process suggests that a process is necessary to deal with FIFO violations in the distribution of blood, which may exist in practice. This assumption is essential to address the high inventory levels at the supplier and to ensure the correct age at distribution to the hospitals for blood types that are routinely over collected relative to demand.

Validation and Verification of the Newfoundland Centre

After incorporating the inventory control policy for the supplier as well as assumptions for dealing with FIFO violations, the baseline Newfoundland model was verified and validated against historic data.

Verification efforts focused on ensuring four of the inputs to the model, including mean centre collections, mean centre imports, mean centre exports and mean hospital demand, matched historic data. Standard statistical tests were used to compare the simulated output against values observed in the historic record for all the four metrics. The mean daily collections, mean centre imports, mean centre exports and mean hospital demand were determined for both the historic records and the simulation model. The baseline model was run for a total of 30 replications of one year (364 days), with a 42-day warm-up period. A prediction interval was then built for the simulation outputs for each of the four metrics. Assuming an alpha level of 5%, it may be concluded that there is no reason to assume that the metrics as observed in the simulation are different from the metrics obtained from the dataset. The results are summarized in Table 3.

	Simulation		Prediction Interval		Historic Mean
	Mean	Variance	Lower Limit	Upper Limit	
Aggregate supplier collections	48.32	1.67	45.64	51.01	46.79
Aggregate supplier import	5.21	0.02	4.90	5.51	5.17
Aggregate supplier export	2.20	0.005	2.06	2.35	2.20
Aggregate hospital demand	48.15	0.12	47.43	48.87	47.89

Table 3- Comparison of centre collections, centre imports, centre exports and hospital demand data for the simulation model against historic data in the Newfoundland centre

To validate the baseline model against the historic dataset the inventory level at the Newfoundland centre, as well as the average age of the distributed stock from the supplier to the hospitals for all the blood types, were compared against the same metrics in the simulation model at an aggregate level. Using a prediction interval approach, and assuming an alpha level of 5%, the mean aggregate inventory from the dataset was compared against the simulation model. The prediction interval approach was used rather than the confidence interval approach, since the historical dataset contains an annual value for only one year. Thus, we lack sufficient data to calculate the variance of metrics derived from the real world data. Therefore, we use a prediction interval, which determines whether or not the single, historical value would be considered to be an anomalous value if generated by the simulation model. The results of the test suggest that the mean supplier inventory, on aggregate could reasonably be generated by the simulation.

	Simulation		Prediction Interval		Historic Mean
	Mean	Variance	Lower Limit	Upper Limit	
Aggregate supplier inventory	489.42	48.09	475.00	503.84	503.47

Table 4- Comparison of supplier inventory for simulation versus historic data in the Newfoundland centre

Using the same test for the average age of the distributed stock to the hospitals by type, it may be assumed that the metrics as obtained from the database, could reasonably be generated by the simulation. We note that the age of B+, is slightly outside of the prediction interval, but assume that is due to the very small variance reported by the simulation. See Table 5.

Average supplier age at distribution by type	Simulation		Prediction Interval		Historic Mean
	Mean	Variance	Lower Limit	Upper Limit	
A-	33.29	5.48	28.43	38.15	30.9
A+	28.98	5.91	23.92	34.03	29.12
AB-	19.28	13.96	11.51	27.05	24.18
AB+	16.82	0.13	16.07	17.57	17.17
B-	26.42	23.72	16.03	36.55	26.02
B+	21.43	0.02	21.17	21.69	21.74
O-	34.16	5.85	29.13	39.19	32.69
O+	31.90	5.41	27.07	36.75	31.24

Table 5- Comparison of supplier average age at distribution by type, for the simulation model against historic data for the Newfoundland centre

Validation and Verification of the Ottawa and BC and Yukon Centre

As in the Newfoundland centre, verification efforts focused on ensuring four of the inputs to the model, including mean centre collections, mean centre imports, mean centre exports and mean hospital demand matched historic data, at both centres. In the Ottawa centre a similar approach was used. Prediction intervals for system metrics, assuming an alpha level of 5%, are summarized in Table 6 for Ottawa and in Table 7 for the BC and Yukon centre. The results show that, at both centres, the metrics as obtained from the database, could reasonably be generated by the simulation.

	Simulation		Prediction Interval		Historic Mean
	Mean	Variance	Lower Limit	Upper Limit	
Aggregate supplier collections	217.88	7.52	212.18	223.58	215.81
Aggregate supplier import	29.08	0.08	28.47	29.68	29.07
Aggregate supplier export	4.28	0.01	4.25	4.31	4.06
Aggregate hospital demand	236.49	0.59	234.89	238.09	235.69

Table 6- Comparison of centre collections, centre imports, centre exports and hospital demand data for the simulation model against historic data in the Ottawa centre

	Simulation		Prediction Interval		Historic Mean
	Mean	Variance	Lower Limit	Upper Limit	
Aggregate supplier collections	326.43	11.26	319.45	33.40	325.72
Aggregate supplier import	54.65	0.25	53.61	55.69	54.56

	Simulation		Prediction Interval		Historic Mean
	Mean	Variance	Lower Limit	Upper Limit	
Aggregate supplier export	1.11	0.002	1.01	1.21	1.11
Aggregate hospital demand	374.63	0.73	372.85	376.41	373.76

Table 7- Comparison of centre collections, centre imports, centre exports and hospital demand data for the simulation model against historic data in the BC and Yukon centre

To validate the baseline model against the historic dataset, the aggregate inventory level at the Ottawa and BC and Yukon centres, as well as the average age of the distributed stock from the both suppliers to the hospitals in their catchment areas, are compared against the same metrics in the simulation model. The prediction interval for the Ottawa centre inventory, assuming an alpha level of 5%, is seen in Table 8. The prediction interval for the BC and Yukon centre inventory, assuming an alpha level of 5%, is seen in Table 9. The tests suggest that the mean supplier inventory, on an aggregate level, could reasonably be generated by the simulation.

	Simulation		Prediction Interval		Historic Mean
	Mean	Variance	Lower Limit	Upper Limit	
Aggregate supplier inventory	2148.47	225.26	2117.26	2179.67	2158.41

Table 8- Comparison of supplier inventory for simulation versus historic data in the Ottawa centre

	Simulation		Prediction Interval		Historic Mean
	Mean	Variance	Lower Limit	Upper Limit	
Aggregate supplier inventory	2979.11	174.61	2951.64	3006.58	2956.21

Table 9- Comparison of supplier inventory for simulation versus historic data in the BC and Yukon centre

Like the Newfoundland centre, an age threshold under which AB+ and B+ units are not distributed from the supplier to the hospitals, was determined empirically. In the Ottawa centre, the age threshold for AB+ is set at 22 days until expiry, while the age threshold for B+, is set at 24 days until expiry. However, for the BC and Yukon centre, the age threshold for AB+ is set at 18 days until expiry, while the age threshold for B+ is set at 29 days until expiry.

The prediction interval results for the age of the stock distributed from the Ottawa centre to the hospitals is summarized in Table 10. The prediction interval results for the age of the stock distributed from the BC and Yukon centre to the hospitals is summarized in Table 11. It may thus be assumed that the metrics as obtained from the database, could reasonably be generated by the simulation, at both centres. We note that the age of B+, is slightly outside of the prediction interval for the Ottawa, but again assume that this is due to the very small variance reported by the simulation.

	Simulation		Prediction Interval		
Average supplier age at distribution by type	Mean	Variance	Lower Limit	Upper Limit	Historic Mean
A-	32.35	5.27	37.12	27.57	31.87
A+	30.63	3.75	26.60	34.65	30.09
AB-	27.20	42.99	13.57	40.83	27.33
AB+	17.67	0.07	17.12	18.22	17.47
B-	31.74	20.40	22.35	41.13	30.76
B+	24.02	0.01	23.80	24.23	23.11
O-	33.80	7.53	28.09	39.45	28.95
O+	30.19	2.46	26.93	33.45	29.78

Table 10- Comparison of supplier average age at distribution by type, for the simulation model against historic data in the Ottawa centre

	Simulation		Prediction Interval		
Average supplier age at distribution by type	Mean	Variance	Lower Limit	Upper Limit	Historic Mean
A-	32.62	4.35	28.28	36.96	30.90
A+	30.52	1.64	27.86	33.19	28.82
AB-	32.63	6.21	27.45	37.81	29.30
AB+	24.26	7.68	18.50	30.02	29.33
B-	33.63	2.48	30.36	36.91	31.70
B+	31.31	1.34	28.90	33.72	30.07
O-	31.57	5.24	26.80	36.32	32.54
O+	27.53	1.21	25.24	29.81	29.80

Table 11- Comparison of supplier average age at distribution by type, for the simulation model against historic data in the BC and Yukon centre

Collections and Demand Based on Canadian Population Distribution

The possibility of substitution between blood types leads many hospitals to choose the most flexible practice of stocking blood types that are compatible with all other blood types, namely O type.

In the same manner, supply centres traditionally over collect more universal blood types, especially O- (as well as AB and B, but for other reasons not relating to product compatibility). Therefore, depending on the size of the hospitals and local hospital ordering practices, it is not uncommon for O type blood to be ordered and used at a rate that is significantly different than that of the population norm. However, it is conceivable that ordering practices could be modified such that blood of a specific group and type is requested at the same rate at which it appears in the Canadian population. In other words, instead of over ordering more universal and high-demand types, primarily O types followed by A types, hospitals could order less universal types of B and AB according to population distribution. Normalizing ordering practices to population means, could lead to a number of advantages, including better product availability and healthier inventory levels for O type blood, at the cost of some increased wastage.

To implement this idea in the simulation cycle, when determining the type of collected units or requested units, instead of using historic collection fractions, Canadian population fractions are used for all blood types. Accordingly, another table was created in the transaction database to store Canadian population fractions for each blood type. Table 12 shows the fractions for each blood type in the Canadian population distribution (Canadian Blood Services, 2016.)

Type	Canadian Population Fraction
A-	6.00%
A+	36.00%
AB-	0.50%
AB+	2.50%
B-	1.40%
B+	7.60%
O-	7.00%
O+	39.00%

Table 12- Percentage of blood types in Canada

In the base model, in which collections are based on historic records and hospitals frequently over order A and O types, it is assumed that the process of type matching between compatible blood

types is already captured in the dataset. Hospitals order universal O type and high demand A type to fill the demand from other blood types, including lower volume AB and B types. Thus, hospitals guard against wastage of low-demand types. The issue of over ordering of O type blood is especially noteworthy in rural facilities and hospitals with low transfusion requirements. This strategy, although reducing wastage at a local level, leads to requirements for unhealthy inventory levels of A and O types and could potentially lead to larger hospital wastage rates for rarer blood types. When blood is collected on the basis of prevalence of blood types within the population and all hospitals order all the blood types, the possibility of type matching among compatible blood types must be explicitly considered in the model. Therefore, a new parameter is also introduced into the simulation that allows type matching between blood types. For compatibility between the eight blood types, see Table 1.

The Newfoundland and Labrador Centre

Newfoundland and Labrador centre, both a production and distribution site, is located in St. John's, Newfoundland. Newfoundland and Labrador is considered a small production and distribution site. It served as the test case for this study.

The list of hospitals that the Newfoundland centre ships blood to, together with their annual demand for RBC units and their distance in kilometers from St. John's are listed in Table 13.

Hospital Name	Annual Demand	Distance From St John's in kilometers
900035 BAIE VERTE PENINSULA HEALTH CARE	4	603
900005 BONAVISTA PENINSULA COMMUNITY HLTH CARE	233	307
900015 BURIN PENINSULA HEALTH CARE CENTRE	629	314
900020 CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	289	2096
900025 CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	1441	427
900030 DR. CHARLES LEGROW HEALTH CENTRE	408	900
900050 CARBONEAR GENERAL HOSPITAL	725	108
900060 DR G B CROSS MEMORIAL HOSPITAL	519	191

Hospital Name	Annual Demand	Distance From St John's in kilometers
900075 GRENFELL REGIONAL HEALTH SERVICES	408	1589
900080 JAMES PATON MEMORIAL HOSPITAL	1203	333
900085 LABRADOR HEALTH SERVICES BOARD	334	1589
900090 PLACENTIA HEALTH CARE CENTRE	169	131
900095 SIR THOMAS RODDICK HOSPITAL	474	765
900110 HEALTH SCIENCES CENTRE	6404	Located in St. John's
900125 ST. CLARE'S MERCY HOSPITAL	2578	Located in St. John's
900135 WESTERN MEMORIAL HOSPITAL	1659	689

Table 13- List of hospitals in the Newfoundland centre catchment area with their annual demand and distance from St John's

The hospitals in Newfoundland and Labrador centre's catchment area, are demonstrated on map in Figure 10.

Figure 10- Location of hospitals in the Newfoundland centre catchment area on map (Google maps)

To prepare the data for use in the simulation models, data preparation routines written by Blake and Hardy (2014) were applied to Newfoundland and Labrador data covering the period between 01 April 2011 and 31 March 2012.

The query results for the Newfoundland supply centre show a total of 38,017 transactions for this time period covering 16 hospitals in our study. These records also include the units imported to or exported from the Newfoundland centre to other CBS centres across Canada.

The Newfoundland centre collects 17,080 units of blood from donors annually and distributes 17,479 units. The centre wastes 775 units annually. The annual amount of imports and exports is 1,887 and 803 units respectively.

The Ottawa and BC and Yukon Centres

Ottawa centre, both a production and distribution site, is located in Ottawa, Ontario. Ottawa is considered a medium-sized production and distribution site. Between 01 April 2011 and 31 March 2012, a total of 179,045 transactions covering 49 hospitals were recorded in Ottawa. These records also include the units imported to or exported from Ottawa to other CBS centres across Canada.

The Ottawa centre collects 78,771 units of blood from donors annually, and distributes 86,028 units. The annual wastage for this centre is 2,087 units. The annual amount of imports and exports is 10,610 and 1,549 units respectively.

The BC and Yukon centre, both a production and distribution site, is located in Vancouver, British Columbia. BC and Yukon is considered a large production and distribution site. The query results for the BC and Yukon supply centre covering the period between 01 April 2011 and 31 March 2012, show a total of 278,278 transactions for this time period, covering the 60 hospitals in our study. These records also include the units imported to or exported from BC and Yukon to other CBS centres across Canada.

The BC and Yukon centre, collects 118,890 units of blood from donors annually, and distributes 136,435 units. The annual wastage for this centre is 2,635 units. The annual amount of imports and exports is 19,913 and 405 units respectively.

Collections and Demand Based on Canadian Population Distribution in the Newfoundland and Labrador Centre

The annual collected units and distribution for all blood types for Newfoundland and Labrador are demonstrated in Table 14. As can be seen in the table, O- annual collection is 12.8%; this is 5.8% above Canadian population distribution. AB+ and B+ are also over collected for reasons other than obtaining RBCs.

Type	Historic collected units	Historic collected distribution	Canadian Population Percentage
A-	1308	7.66%	6.00%
A+	5073	29.70%	36.00%
AB-	80	0. 46%	0.50%
AB+	390	2.29%	2.50%
B-	226	1.32%	1.40%
B+	1154	6.76%	7.60%
O-	2184	12.8%	7.00%
O+	6665	39.00%	39.00%

Table 14- Historic annual collected units/distribution by the Newfoundland centre versus Canadian population distribution

The annual demand for units and their distribution in Newfoundland and Labrador is demonstrated in Table 15 . It can be seen that O- use is 140% above the expected population demand, (or 9.8% in absolute terms), while the demand for less universal types of AB+ and B+ is much lower than the population distribution.

Type	Historic Aggregate hospital demand	Historic Aggregate hospital demand distribution	Canadian Population Percentage
A-	1684	9.63%	6.00%
A+	5308	30.37%	36.00%
AB-	65	0.37%	0.50%
AB+	103	0.59%	2.50%
B-	167	0.96%	1.40%
B+	509	2.91%	7.60%
O-	2939	16.81%	7.00%
O+	6704	38.35%	39.00%

Table 15- Historic annual demanded units/distribution by hospitals in Newfoundland versus Canadian population distribution

To demonstrate demand, a small hospital in Newfoundland and Labrador region, the Bonavista Peninsula Community Healthcare, is presented below. Historic demand distribution for this small hospital is demonstrated in Table 16. As can be seen in the table, the historic demand is limited to A and O types, with A-, A+ and O- percentages being ordered and transfused at much higher rate than would be expected, given the distribution of blood types in the Canadian population.

Type	Historic Demand	Canadian Population Percentage
A-	12.90%	6.00%
A+	39.05%	36.00%
AB-	0.00%	0.50%
AB+	0.00%	2.50%
B-	0.00%	1.40%
B+	0.00%	7.60%
O-	16.30%	7.00%
O+	31.80%	39.00%

Table 16- Percentage of annual demand for each blood type in a small hospital in the Newfoundland historic dataset versus Canadian population distribution

To carry out the study under assumptions of normalized collections and demand, in the simulation cycle, while determining the ABO and Rh of the collected and demanded blood, the Canadian population distribution for blood types is used instead of the historic data. The historically collected units in the Newfoundland centre versus Canadian population based collections are demonstrated in Table 17. For instance, in the historic dataset, A- collections are 1308 units per annum, whereas after switching to Canadian population fractions, A- collections goes down to 1024.8 units.

Type	Historic collected units	Canadian Population collected units	Historic Population Percentage	Canadian Population Percentage
A-	1308	1024.80	7.66%	6.00%
A+	5073	6148.80	29.70%	36.00%
AB-	80	85.40	0.47%	0.50%
AB+	390	427.00	2.28%	2.50%
B-	226	239.12	1.32%	1.40%
B+	1154	1298.08	6.76%	7.60%

Type	Historic collected units	Canadian Population collected units	Historic Population Percentage	Canadian Population Percentage
O-	2184	1195.60	12.78%	7.00%
O+	6665	6661.20	39.02%	39.00%

Table 17- Historic annual collected units by the Newfoundland centre versus collected units based on Canadian population distribution.

To adjust ordering levels at hospitals to match demand based on the Canadian population, the demand at each hospital is summed and then re-distributed based on the population distribution to calculate the number of units that should have been requested. For a comparison of historic demand in Bonavista Peninsula Community Health Care versus new redistributed demand, assuming all types are ordered based on Canadian population fractions, see Table 18 and Table 19. For instance, in the historic dataset, the demand for A- type is 30 units, while in the new scenario, based on population distribution, this demand would only be expected to be 13.98 units.

Type	Number of Demanded Units	Percentage
A-	30	12.90%
A+	91	39.10%
O-	38	16.30%
O+	74	31.80%

Table 18- Percentage of historic demand in a small hospital in Newfoundland

Type	Number of Demanded Units	Percentage
A-	13.98	6.00%
A+	83.88	36.00%
AB-	1.17	0.50%
AB+	5.83	2.50%
B-	3.26	1.40%
B+	17.71	7.60%
O-	16.31	7.00%
O+	90.87	39.00%

Table 19- Percentage of re-distributed demand in a small hospital in Newfoundland

Finally, in the new scenario, imports and exports are also adjusted to be identical to Canadian population fractions. The difference in imported and exported units for historic versus Canadian

Population, is shown in Table 20 and Table 21. In the historic scenario the imports of A- type are 471.75 units per year, while the exports are 21 units. However, in the new scenario, which is based on the population distribution of blood types, A- imports are 113.22, while 48.18 units would be expected to be exported daily.

Type	Historic imported units	Canadian Population imported units
A-	471.75	113.22
A+	339.66	679.32
AB-	18.87	9.44
AB+	0.00	47.18
B-	18.87	26.42
B+	0.00	143.41
O-	830.28	132.09
O+	207.57	735.93

Table 20- Historic imported units by the Newfoundland centre versus imported units based on Canadian population distribution

Type	Historic Exported units	Canadian Population Exported units
A-	21	48.18
A+	98	289.08
AB-	4	4.02
AB+	6	20.08
B-	86	11.24
B+	227	61.03
O-	93	56.21
O+	268	313.17

Table 21- Historic exported units by the Newfoundland centre versus exported units based on Canadian population distribution

A further issue in this scenario is determining an order policy for blood types that were not previously ordered. For instance, a hospital may have never ordered AB- units. In the new scenario, hospitals that formerly ordered more universal blood types, A and O, also order less universal types, namely B and AB. To illustrate these changes, below we discuss the case of Bonavista Peninsula Community Health Care. For this hospital, the previous order up to points were provided by the hospital and are based on experience over a long period of time. From this data we can obtain the maximum,

minimum and average mean days on hand for A and O blood groups. Please note, mean days on hand (MDOH) are obtained by dividing the historic order up to points for historically ordered A/O types by mean historic daily demand. For example, the historic order up to point for A-, is 2 units. After dividing 2 units by historic average daily demand for this type, (30 units per year/364 days per year =0.0824 units per day), MDOH for A- is calculated as 2/0.0824 = 24.27 days. The historic MDOH for the rest of the types requested by BPCHC are: 8.00 (A+), 19.16 (O-) and 9.84 (O+) days, respectively. Therefore, the maximum MDOH for Bonavista Peninsula Community Health Care is 24.27 days, the minimum MDOH is 8 days and the average MDOH is 15.32 days.

Once mean days on hand was calculated, these values were used to find estimated order up to and order trigger points for any newly ordered blood types. For example, AB- was not ordered in the historic policy, but 1.165 units should have been ordered. Therefore, to get the new order up to point for AB-, the maximum, the minimum and the average mean days' demand for A/O blood types for this hospital, are multiplied by the mean daily demand for this type (1.165/364=0.0032), to identify a range of potential order points. For AB-, 0.077 is identified as the maximum MDOH order up to point, 0.026 as the minimum MDOH order up to point and 0.049 as the average MDOH order up to point. However, since fractional units are not possible, fractional order up to points are always rounded to the nearest unit, in this case, 1.

Trigger points are calculated in a similar fashion. To obtain the new trigger points for AB-, the mean daily demand for the blood type, based on Canadian population distribution (0.0032), is multiplied by the mean number of days observed between orders at Bonavista Peninsula Community Health Care in the historic record (3.059 days) to obtain the expected demand between orders as (0.0032*3.059 = 0.0098) units. To obtain trigger points, the expected demand between orders is later subtracted from the three new order up to points. Therefore, the new order trigger points are respectively (0.077 – 0.0098 = 0.0679), (0.026 – 0.0098 = 0.0158) and (0.049 – 0.0098 = 0.0392) for maximum, minimum and

average MDOH. Any fractional trigger points are however rounded down to the next smallest integer value. As can be seen, for all the three new ordering policies, order trigger points are set at 0. Zero trigger points for less universal types are common in most hospitals, especially in small, remote ones, since the distribution of these types within the population is very small. This decision implies, of course, that rare types are ordered only as required, typically as an emergency unit. For blood types that were historically ordered, including A and O types, (s, S) values are altered only if the daily demand has changed when based on Canadian population distribution. For example, historically, 30 units of A- were ordered at BPCHC, whereas in the new scenario only 13.98 units are assumed to be ordered. Therefore, to get the new order up to point (S) for A- blood, the new average daily demand (13.98/364=0.0384) is multiplied by the historic MDOH for A-, in the historic data (24.27 days) to obtain 0.03884 * 24.27 = 0.932 units. This value, however, is rounded up to 1 day. In the same manner as calculating order trigger points for the newly added types, new mean daily demand for A- (0.0384) is multiplied by the mean number of days observed between orders at Bonavista Peninsula Community Health Care, 3.059 days, to obtain the expected demand between order epochs (0.0384 * 3.059 = 0.1175 units). This number is later subtracted from the calculated order up to point (0.932). Therefore, the new order trigger point is 0.932 – 0.1178 = 0.815, which is again rounded down to 0. For a list of historic order up to and order trigger points versus new population distribution order up to and order trigger points for Bonavista Peninsula Community Health Care, see Table 22.

Type	Historic(s, S)	MaximumMDOH(s, S)	MinimumMDOH(s, S)	AverageMDOH(s, S)
A-	(1,2)	(0,1)	(0,1)	(0,1)
A+	(0,2)	(1,2)	(1,2)	(1,2)
AB-	(0,0)	(0,1)	(0,1)	(0,1)
AB+	(0,0)	(0,1)	(0,1)	(0,1)
B-	(0,0)	(0,1)	(0,1)	(0,1)
B+	(0,0)	(1,2)	(0,1)	(0,1)
O-	(1,2)	(0,1)	(0,1)	(0,1)

Type	Historic(s, S)	MaximumMDOH(s, S)	MinimumMDOH(s, S)	AverageMDOH(s, S)
O+	(1,2)	(1,3)	(1,3)	(1,3)

Table 22- Historic versus maximum, minimum and average MDOH ordering policies for added blood types in a small hospital in Newfoundland

The three methods for calculating (s,S) for the newly added blood types were evaluated by running the simulation for 30 replications of 364 days with a warm-up period of 42 days, under the assumption of type matching between compatible blood types. System metrics, including blood wastage, shortage and emergency orders for all blood types for each order policy were compared against one another. However, the metrics cover different operational concerns. Accordingly, to avoid a multi-dimensional comparison, weights were subjectively applied to each of the metrics to determine a single weighted output value. In this scenario, the largest weights were given to shortages, with O- shortages weighted at twice that of the other types. The smallest weight was assigned to aggregate wastage across hospitals. The weights given to each metric are listed in Table 23.

Metric	Weight
Emergency order for all blood types	5
Aggregate wastage across all hospitals	1
A- Shortage	10
A+ shortage	10
AB- shortage	10
AB+ shortage	10
B- shortage	10
B+ shortage	10
O- shortage	20
O+ shortage	10

Table 23- Weights given to system metrics

By multiplying the weights and the hospital shortage and emergency orders for each type and adding that to weighted aggregate hospital wastage, after the simulation is run, a single output for each ordering policy is obtained. As can be seen in Table 24, after penalizing shortages, emergency orders and wastage by the values in Table 23, the maximum mean days on hand policy, gives the smallest value and therefore is assumed to be the most favorable policy. Thus, for the purposes of comparison between the

historic and new ordering policies, it is assumed in all runs that (s,S) policies are calculated using the maximum MDOH of A and O type blood.

Maximum A/O MDOH KPI	Average A/O MDOH KPI	Minimum A/O MDOH KPI
5.84	6.47	6.4

Table 24-KPI of maximum/minimum/average MDOH of A and O types in terms of hospital shortage, wastage and emergency orders in the Newfoundland centre

For a list of historic versus new (s, S) see Appendix C.

Collections and Demand Based on Canadian Population Distribution in the Ottawa and BC and Yukon Centre

To carry out the study under assumptions of normalized collections and demand in the simulation cycle, while determining the ABO and Rh of the collected and demanded blood, the Canadian population distribution for blood types are used instead of the historic data at both the Ottawa and at the BC and Yukon centres. To adjust ordering levels at hospitals to match demand based on the Canadian population, the demand at each hospital is summed and then re-distributed based on the population distribution to calculate the number of units that should have been requested. In the new scenario, imports and exports are also adjusted to be identical to Canadian population fractions.

To determine an order policy for blood types that were not previously ordered, the maximum, minimum and average mean days on hand for A and O blood groups in the historic data were obtained at both centres. The order up to and order trigger points for the newly added types are calculated for each scenario. For blood types that were historically ordered, including A and O types, (s, S) values are altered only if the daily demand has changed when based on Canadian population distribution. Like the Newfoundland centre, the three methods for calculating (s,S) for the newly added blood types were evaluated by running the simulation for 30 replications of 364 days with a warm-up period of 42 days. System metrics, including blood wastage, shortage and emergency orders for all blood types for each order policy were compared against one another. The same weights, as in the Newfoundland centre, listed in Table 23, were assigned to the metrics of interest. After penalizing shortages, emergency orders

and wastage, the average MDOH policy, for the Ottawa centre and the maximum MDOH policy, for the BC and Yukon centre, gives the smallest value and therefore is the most favorable policy. See Table 25 and Table 26 for the comparison of the three MDOH based policies in the Ottawa and BC and Yukon centres. Thus, for the purposes of comparison between the historic and new ordering policies, it is assumed in all runs that (s, S) policies are calculated using the average MDOH of A and O type blood in the Ottawa centre, while it is assumed that (s, S) policies are calculated using the maximum MDOH of A and O type blood, in the BC and Yukon centre.

Maximum A/O MDOH KPI	Average A/O MDOH KPI	Minimum A/O MDOH KPI
17.82	15.93	20.52

Table 25- KPI of maximum/minimum/average MDOH of A and O types in terms of hospital shortage, wastage and emergency orders in the Ottawa centre

Maximum A/O MDOH KPI	Average A/O MDOH KPI	Minimum A/O MDOH KPI
31.93	33.72	38.73

Table 26- KPI of maximum/minimum/average MDOH of A and O types in terms of hospital shortage, wastage and emergency orders in the BC and Yukon centre

For a list of historic versus new (s, S) see Appendix C.

Chapter 4 Experiments

Baseline Scenario

To create a baseline scenario, the model was run under the assumption of historic ordering practice with historic collections, demand, and exports. Assumptions underlying the baseline scenario include:

1. The baseline scenario is run for 30 replications for 364 days, under the method of replication/deletion. The selection of 30 replications, which is a convenience sample, is assumed for normality reasons. The selection of 30 replications provides an acceptable absolute error on the key metrics of wastage, shortages, and emergency orders. For a calculation of standard error on mean daily shortage for all types see Table 27.

Type	Mean	σ	Standard Error
A-	0.02	0.03	0.01
A+	0.00	0.01	0.00
AB-	0.01	0.01	0.00
AB+	0.00	0.00	0.00
B-	0.02	0.01	0.01
B+	0.00	0.00	0.00
O-	0.03	0.04	0.01
O+	0.00	0.01	0.00

Table 27- Calculated standard error on baseline hospital shortage mean in the Newfoundland centre

2. At the beginning of each replication it is assumed that the sum of target levels (S) of all hospitals is allocated to the supplier at random age buckets. This way, the system does not start empty and the supplier is able to fill hospital orders starting on day one.
3. The simulation is first run for a warm-up period of 42 days, before statistics are collected. A 42 day warm-up period is used because the shelf-life of the blood is 42 days and thus any starting inventory is necessarily eliminated from the simulation after 42 days. The 42-day

warm-up period was also confirmed using the Welch technique as described in Law (2006), with aggregate supplier inventory as the metric of interest. For the warm-up period confirmation, using the Welch technique, see Appendix E.

4. Aggregate collections were adjusted up to a predetermined level per day by comparing a seven day moving average of historic target inventory and simulation inventory.
5. A modified FIFO policy is applied to the over collected types of AB+ and B+, so that units that are older than a certain age are not issued to hospitals. For the Newfoundland and Labrador centre, AB+ units older than 21 days until expiry and B+ units older than 15 days until expiry are not distributed to hospitals in the simulation.
6. The distribution of units imported to Newfoundland and Labrador is modified to compensate for the inventory depletion in high demand but less frequently ordered A types, especially A-.
7. The baseline scenario is used as a benchmark to evaluate the new ordering policy based on the blood type distribution of the Canadian population.

The baseline scenario was run for 30 replications of 364 days with a warm-up period of 42 days. The metrics of interest included the inventory level at the supplier and the wastage, shortage and emergency orders at the hospitals. The daily average metrics were recorded for all blood types.

An overall wastage rate of 3.1% of average daily demand was observed across all hospitals in the Newfoundland and Labrador area. The overall shortage rate was recorded at 0.2% of the demand. Moreover, the hospitals placed emergency orders (orders placed by a hospital outside of the regular order cycle in response to a demand that could not be filled by stock on hand) at a rate equal to 1.2% of the demand.

The data shows that Rh positive types have higher inventory levels at the supplier, due to the higher prevalence of these blood types in the population, with A+ and O+ accounting for the highest inventory

on hand. Figure 11 shows the distribution of supplier inventory by type in the baseline scenario, for the Newfoundland centre.

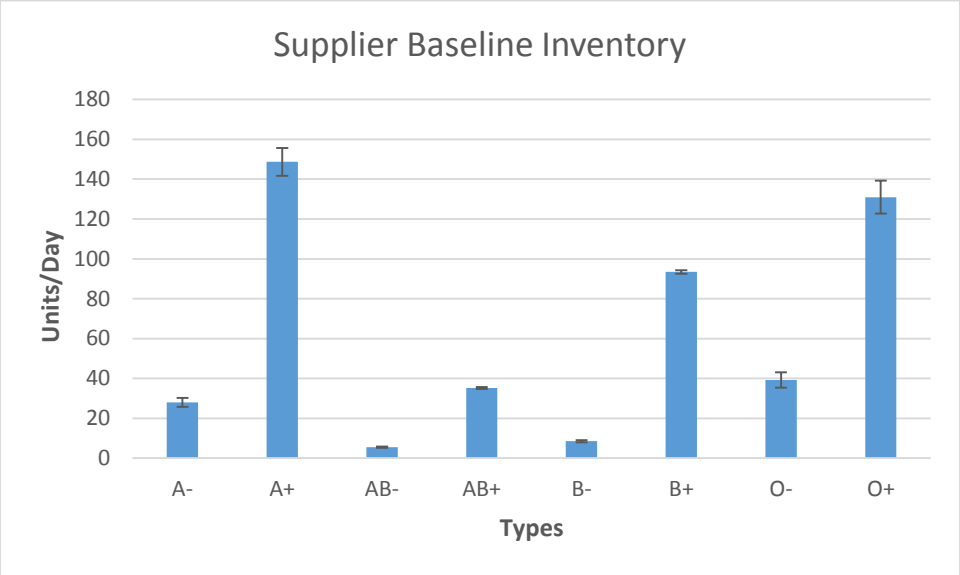

Figure 11- Distribution of the baseline scenario supplier inventory level, by type, in the Newfoundland centre

The data also shows that most shortages occur among Rh negative types with O- followed by A-, accounting for the greatest number of shortages. Figure 12 illustrates the distribution of hospital shortage by type in the baseline scenario for the Newfoundland centre.

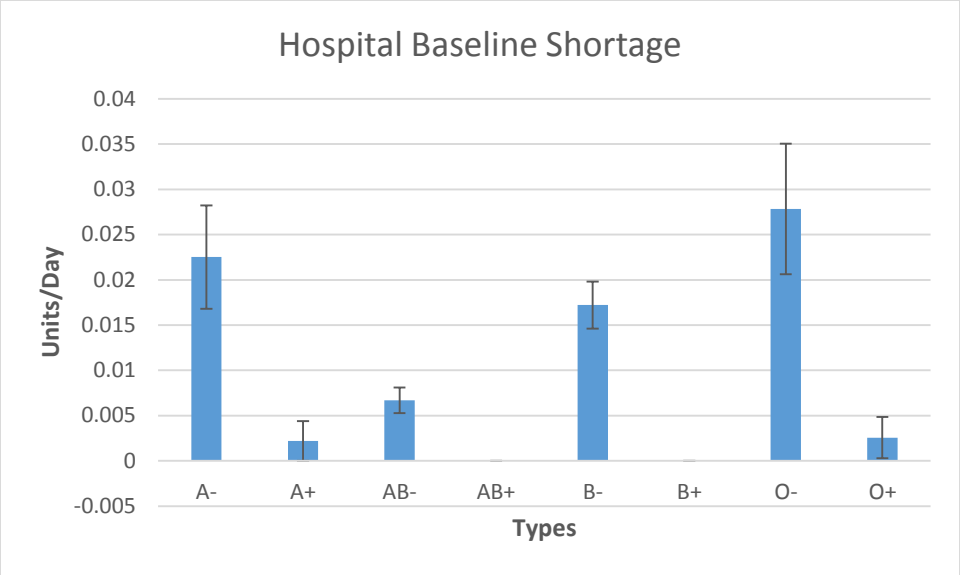

Figure 12- Distribution of the baseline scenario hospital shortage, by type, in the Newfoundland centre

However, wastage is more equally distributed across all types with Rh positive types generally representing the largest volume of wastage. A+ followed by A-, account for the highest amount of wastage. Surprisingly, A- accounts for both high amounts of shortages and wastage, due to the fact that many hospitals, especially small remote ones, rely on this type to fill a significant proportion of their inventory to ensure a good level of compatible group matching. Figure 13 demonstrates the distribution of hospital wastage by type in the baseline scenario for the Newfoundland centre.

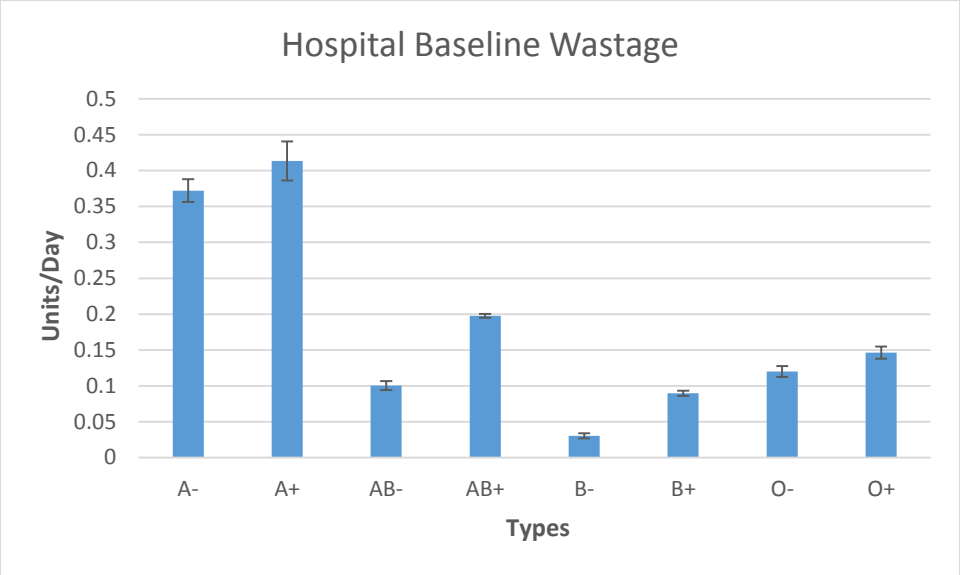

Figure 13- Distribution of baseline scenario hospital wastage, by type, in the Newfoundland centre

Emergency orders are also distributed among all types (both Rh negative and positive.) See Figure 14 for the distribution of hospital emergency orders in the baseline scenario for the Newfoundland centre.

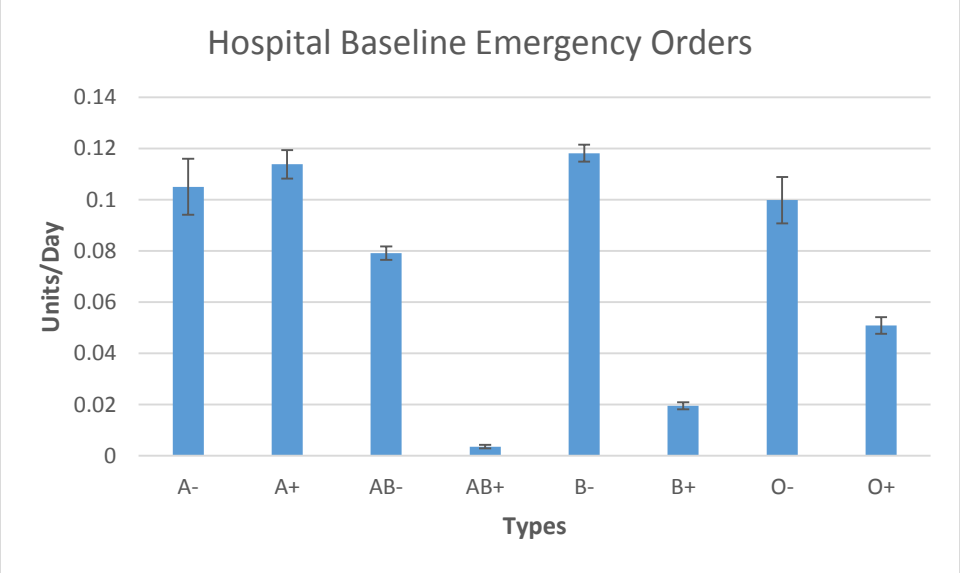

Figure 14- Distribution of the baseline scenario hospital emergency orders, by type, in the Newfoundland centre

New Scenario

To attain a new ordering policy based on the Canadian population distribution, annual collection rates are assumed to match the blood type distribution of the Canadian population. It is also assumed all hospitals order blood types at a rate equivalent to that within the Canadian population. To do so, demand is aggregated at each hospital and blood types redistributed based on the Canadian population distribution. Trigger and order up to points for any newly added types, in the case of Newfoundland and Labrador, are based on the average mean days on previously ordered A and O types which are then used to recalculate new (s, S) for the newly added types. (s, S) levels for the previously ordered A and O types, are only altered if their fractions have changed in the new scenario. The new scenario also assumes that product substitution is allowed at both hospitals and at the supplier. In addition, imports and exports at the centre are adjusted to population means to ensure a balanced supply and demand.

In the same manner as the baseline scenario, the new scenario is run for 30 replications of 364 days following a warm-up period of 42 days. The same metrics of interest, namely the average daily inventory level at the supplier and the average daily wastage, shortage and emergency order levels at the hospitals, are recorded for all types. The objective of the study is to determine how the metrics in the Newfoundland and Labrador blood supply are affected if collection, imports, demand and exports are switched to such that the blood type distribution in each is equivalent to that of the Canadian population. Specifically, we focus on O- metrics, as the most transfusable type, because it is a common practice to over order O-. Thus we hypothesize that switching to population percentages in both collections and demand should ease the burden on the O- requirements. However, since it is also likely that some O- inventory will likely be needed to support compatibility matching at remote locations, we also hypothesize that it may be necessary to have some level of O- over collection to avoid large scale shortages throughout the system. Therefore, the new scenario is also used to determine by how much O- collections must be increased to achieve zero hospital shortages for all types.

Results

After switching to the new policy, the overall wastage rate across hospitals rises to 4.7% of average daily demand. While the average shortage stays at 0.2% of the demand, hospitals place fewer emergency orders, averaging 0.7% of the demand.

Considering the metrics, by type, it is evident that the change from the baseline scenario is mostly statistically significant. With the null hypothesis of equal means, at 5% alpha level, the tests, comparing the baseline scenario metrics against the new scenario metrics, are mostly rejected. See Table 28 to Table 31 for statistical tests of comparing the baseline metrics against the new scenario metrics.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	28.01	5.75	12.27	3.32	0.00
A+	148.69	195.12	38.15	37.74	0.00
AB-	5.48	0.58	1.40	0.09	0.00
AB+	35.15	6.09	2.49	2.51	0.00
B-	8.47	1.77	3.50	0.74	0.00
B+	93.42	21.76	5.02	10.52	0.00
O-	39.25	13.78	20.83	6.39	0.00
O+	130.95	255.96	45.26	40.63	0.00

Table 28- Statistical test to compare the baseline supplier inventory mean against the new scenario supplier inventory mean in the Newfoundland centre. All results are statistically significant at the $\alpha = 5\%$ level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.37	0.27	0.09	0.05	0.00
A+	0.41	0.65	0.15	0.15	0.00
AB-	0.10	0.10	0.03	0.02	0.90
AB+	0.20	0.23	0.01	0.04	0.00
B-	0.03	0.16	0.02	0.02	0.00
B+	0.09	0.33	0.02	0.09	0.00
O-	0.12	0.14	0.04	0.04	0.07
O+	0.15	0.39	0.05	0.11	0.00

Table 29- Statistical test to compare the baseline hospital wastage mean against the new scenario hospital wastage mean in the Newfoundland centre. All values are significantly different except in instances where the p-value (highlighted) is above 0.05.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.02	0.01	0.03	0.02	0.20
A+	0.00	0.00	0.01	0.00	0.30
AB-	0.01	0.00	0.01	0.00	0.00
AB+	0.00	0.00	0.00	0.00	0.00
B-	0.02	0.00	0.01	0.01	0.00
B+	0.00	0.00	0.00	0.00	0.00
O-	0.03	0.09	0.04	0.07	0.00
O+	0.00	0.00	0.01	0.00	0.30

Table 30- Statistical test to compare the baseline hospital shortage mean against the new scenario hospital shortage mean in the Newfoundland centre. . All values are significantly different except in instances where the p-value (highlighted) is above 0.05.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.11	0.07	0.06	0.05	0.03
A+	0.11	0.00	0.03	0.00	0.00
AB-	0.08	0.00	0.01	0.00	0.00
AB+	0.00	0.00	0.00	0.00	0.00
B-	0.12	0.02	0.02	0.01	0.00
B+	0.02	0.00	0.01	0.00	0.00
O-	0.10	0.20	0.05	0.10	0.00
O+	0.05	0.01	0.02	0.01	0.00

Table 31- Statistical test to compare the baseline hospital emergency order mean against the new scenario hospital emergency order mean in the Newfoundland centre. All results are statistically significant at the $\alpha = 5\%$ level.

From Table 28 to Table 31, it may be concluded that the effect on the various performance metrics is not evenly distributed across all types. With regard to supplier inventory level, there is a reduction in all types, except for A+ and O+ (significant at the 5% level, given a one-sided t-test). The supplier inventory for A+ increases, due to the fact that its collection, based on Canadian population distribution, is larger in the new scenario; A+ aggregate collection in the baseline scenario is 29.7%, whereas in the new scenario A+ collection accounts for 36% of all collections (See Table 14). The percentage for O+ does not change from the baseline scenario to the new scenario and stays at 39%. In the new scenario since all types are ordered, less demand is filled from O+ through compatible type matching; this explains the increase in O+ supplier level in the new scenario. Note that the change from the baseline to the new scenario is significant for all types under a one-sided t-test**.** See Appendix F for one-sided t-tests of comparing the baseline metrics against the new scenario metrics. For a graphical comparison of the baseline scenario supplier inventory versus the new scenario, see Figure 15.

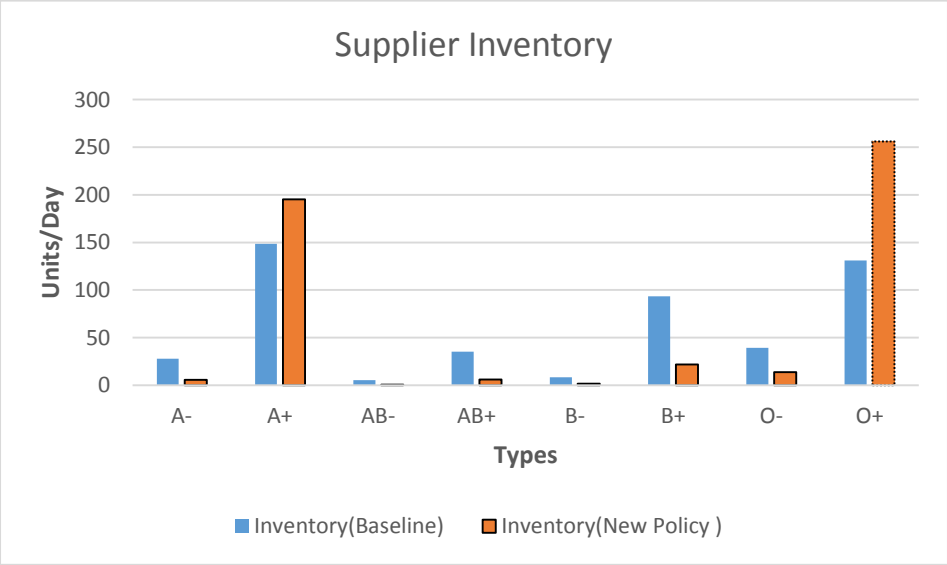

Figure 15- Comparison of the baseline scenario supplier inventory versus the new scenario, by type, in the Newfoundland centre

Statistically significant increases in wastage were observed in the new scenario for all blood types except for AB-, for which changes were not significant, and for A- wastage which were observed to

decrease in the new scenario. The increase in wastage in less universal types of AB+, B- and B+ is due to the fact that they were not generally ordered in the baseline scenario, but are ordered in the new scenario. However, since the demand from these types remain small in the new scenario, they are outdated more often. The increase in wastage of O+ and A+ is consistent with their supplier inventory level. All increases or decreases in wastage were statistically significant at the 5% level, except for AB- wastage, for which changes were not significant. See Appendix F for one-sided t-tests of comparing the baseline metrics against the new scenario metrics. For a graphical comparison of the baseline scenario hospital wastage, versus the new scenario, see Figure 16.

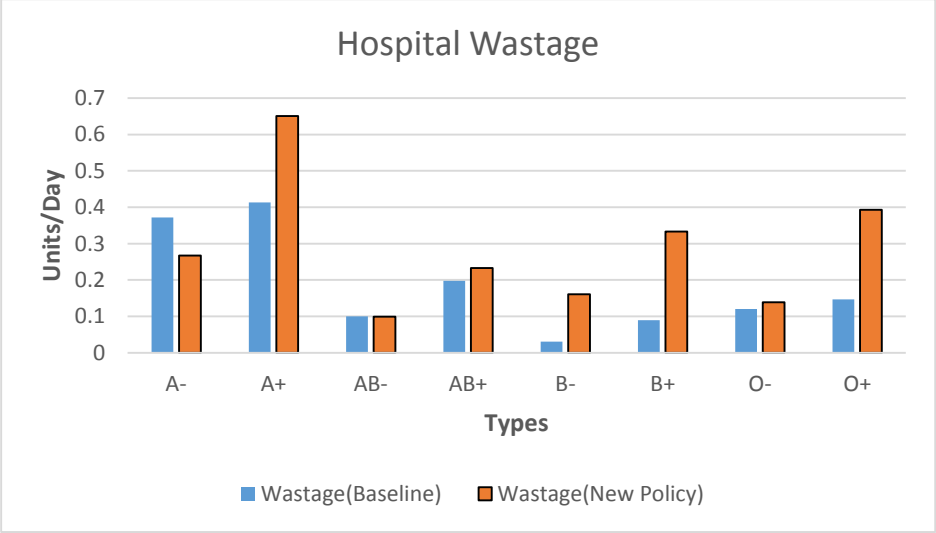

Figure 16- Comparison of the baseline scenario hospital wastage versus the new scenario, by type, in the Newfoundland centre

However, system-wide wastage decreases, due to the fact that in the new scenario, the two non-universal types of AB+ and B+ are not over collected, but collected based on Canadian population means. Therefore, as the system-wide wastage decreases considerably for these two types, in the new scenario, a decrease in the overall wastage is witnessed in the new scenario. Wastage for all the other types closely resemble hospital wastage, illustrated in Figure 16. The similarity between hospitals wastage and system-wide wastage (except for AB+ and B+ types) indicates that wastage is almost always

observed at hospitals. For a graphical comparison of the baseline scenario system-wide wastage, versus the new scenario, see Figure 17.

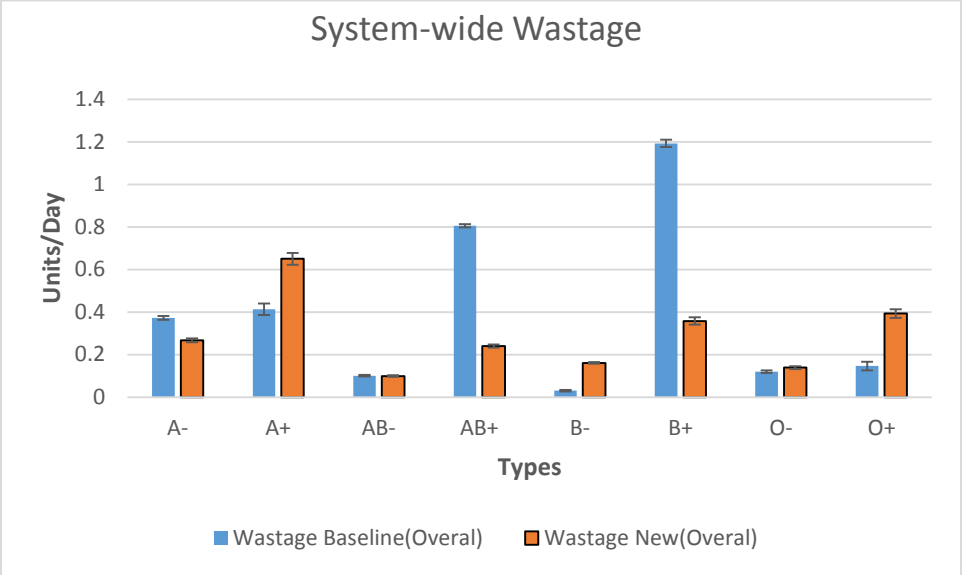

Figure 17- Comparison of the baseline scenario system-wide wastage versus the new scenario, by type, in the Newfoundland centre

The impact of the new scenario is, predictably, most apparent in the O- shortage level. O- shortage rises significantly ($\alpha = 5\%$) from the baseline scenario to the new scenario, since the aggregate collection level drops from 12.8% in the baseline scenario to 7% in the new scenario. Moreover, since demand from any other type can be filled with O- during a local shortage of a particular type, there may not be enough O- stock on hand to meet demand from O- patients. Note that shortage rates for all other blood types go down, except for AB+ and B+ which have zero shortages in both the scenarios; no shortage is seen across any of Rh positive types in the new scenario. However, one-tailed tests show that the changes in the shortage rate for A-, A+ and O+ are not statistically significant. See Appendix F for one-sided t-tests of comparing the baseline metrics against the new scenario metrics. For a graphical comparison of the baseline scenario hospital shortage, versus the new scenario, see

Figure 18.

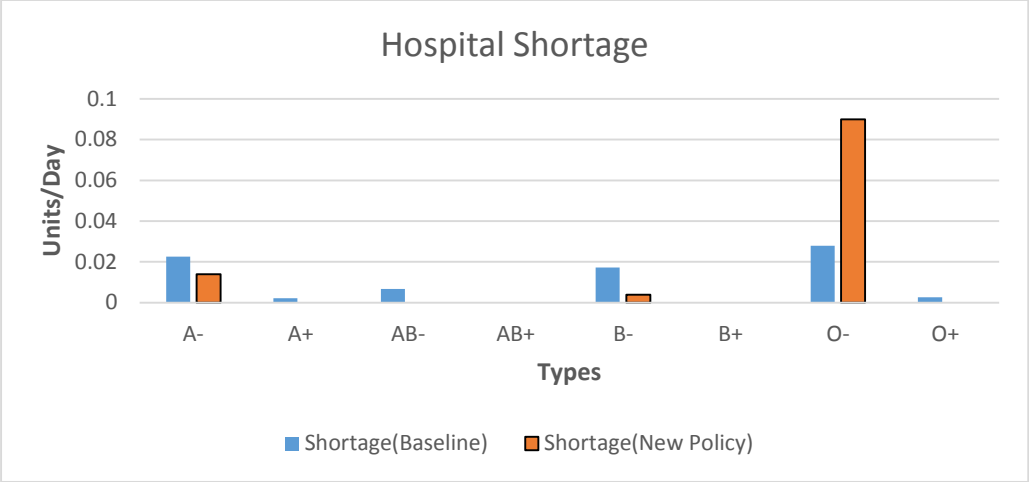

Figure 18- Comparison of the baseline scenario hospital shortage versus the new scenario, by type, in the Newfoundland centre

Hospital emergency orders closely follow shortages after the switch from the baseline to the new scenario. O- emergency orders rise in the new scenario, while the emergency orders decrease for all the other types. However, there is still a small amount of emergency orders in the new scenario for all the types, including Rh positive types. Note that the change from the baseline to the new scenario are considered statistically significant for all types under a one-sided t-test at the 95% certainty level. . See Appendix F for one-sided t-tests of comparing the baseline metrics against the new scenario metrics. For a graphical comparison of the baseline scenario hospital emergency orders, versus the new scenario, see Figure 19.

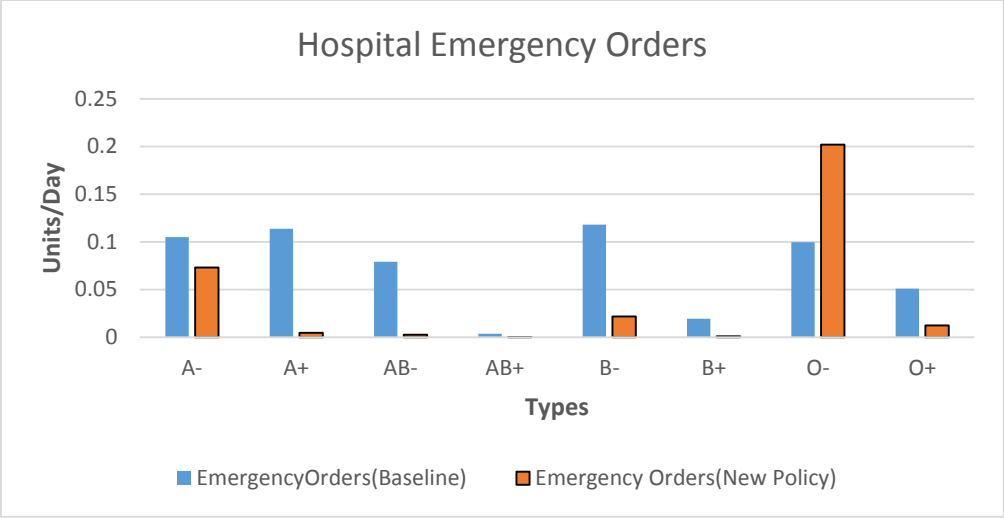

Figure 19- Comparison of the baseline scenario hospital emergency orders versus the new scenario, by type, in the Newfoundland centre

O- Over Collection to Achieve Zero Hospital Shortage Rates

As the results show, switching to the new policy, would lead to a higher shortage rate across hospitals in the Newfoundland area. Therefore, it was decided to introduce a new factor into the model that increases daily O- collections, such that zero shortages can be achieved for all types. To determine by how much O- collection needs to be increased over its population percentage of 7%, experiments were conducted with this extra collection percentage. These experiments involved iteratively increasing O- collection from 1% by 0.1% and recording the resulting shortages. Shortages only occur in A-, B- and O- type blood. The results show however that increasing daily collections by 1.4% (and dedicating this amount to O- collections) would result in zero hospital shortages for all types. For a plot of shortage rates at various O- over collection over 7% see Figure 20.

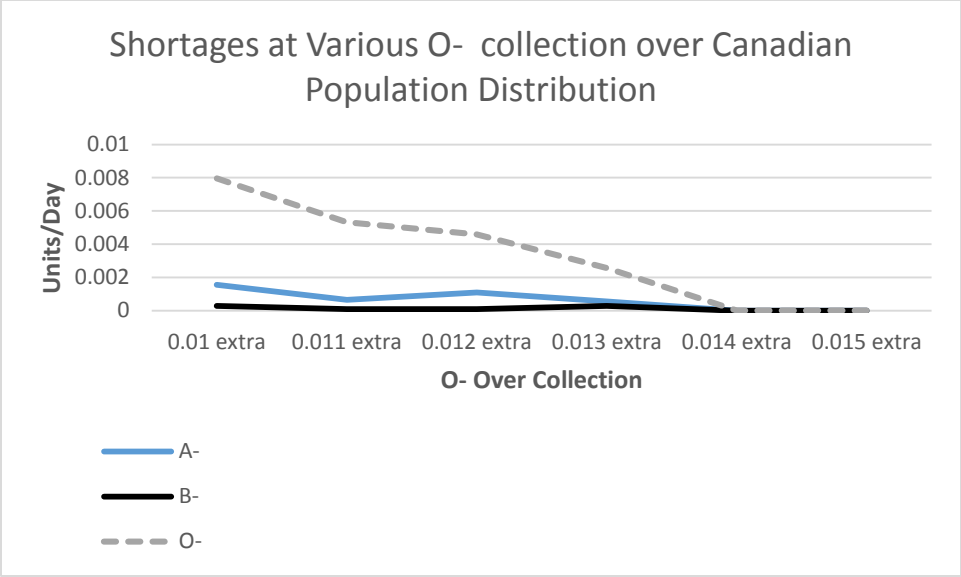

Figure 20- Shortages recorded at various O- collection over population distribution in the Newfoundland centre.

Increasing O- collections would lead to higher wastage; by over collecting O- by 1.4% above the 7% level seen in the Canadian population distribution, hospital wastage would increase from 3.1% of average daily demand to 4.79% of average daily demand. After multiplying the O- Canadian population percentage by 1.014%, and then normalizing the resulting distribution, the new collection distribution is obtained. The new percentages are listed in Table 32.

Type	Canadian Population Percentages	Scenario Collection	Normalized Percentages	Historic Percentages
A-	6.00%	6.00%	5.99%	7.70%
A+	36.00%	36.00%	35.97%	29.70%
AB-	0.50%	0.50%	0.50%	0.50%
AB+	2.50%	2.50%	2.50%	2.30%
B-	1.40%	1.40%	1.40%	1.30%
B+	7.60%	7.60%	7.59%	6.80%
O-	7.00%	7.10%	7.09%	12.80%
O+	39.00%	39.00%	38.96%	39.00%
Total	100.00%	100.10%	100.00%	100.00%

Table 32- New collection percentages after increasing O- collection to achieve zero shortage rates for all types versus Canadian population percentages and historic collection percentages, for the Newfoundland centre

As can be observed in Table 32, switching to the new scenario reduces O- collections from 12.8%, as observed in historic dataset, to 7.09%.

Study Expansion to a Medium and a Large Centre across Canada

In the following sections, the Canadian population study is applied to two other blood supply centres in Canada: Ottawa, a medium centre; and BC and Yukon, a large centre. As was the case with the Newfoundland centre, to get a realistic version of the actual system, a baseline model was developed and validated, for each centre. The validation process is similar to the process in the Newfoundland centre, with minor modifications. At each site, the baseline scenario is later compared against a new scenario, in which collections, imports, demand and exports are based on Canadian population distribution. Like the study in the Newfoundland centre, the objective is to evaluate how system metrics are impacted by moving from the baseline to the new scenario. Finally, a collection percentage over the Canadian population percentage for O- that achieves zero shortages across all types is determined through an iterative experimental process.

Ottawa Centre Results

To create a baseline scenario for the Ottawa centre, the same underlying assumptions as in the Newfoundland centre were adopted. However, to account for FIFO violations occurring in the distribution of over collected types, namely AB+ and B+, two new thresholds are selected. These are the age thresholds, below which, stock will not be distributed from the supplier to hospitals. The threshold for AB+ was determined to be 22 days until expiry, while the threshold for B+ was set at 24 days until expiry. Unlike the Newfoundland centre, the historic number and distribution for imports is used without any modifications.

In the same manner as the Newfoundland centre, the baseline scenario in the Ottawa centre was run for 30 replications of 364 days with a warm-up period of 42 days. The daily average metrics for supplier inventory level and hospital wastage, shortage and emergency order rates were recorded for all blood types.

An overall wastage rate of 0.46% of average daily demand is observed across all hospitals in the Ottawa area. The overall shortage rate is recorded at 0.06% of the demand; hospitals placed emergency orders at a rate equal to 1.54% of the demand.

The results show that Rh positive types have higher inventory levels at the supplier, compared to Rh negative types, due to the higher prevalence of these blood types in the population, with A+ and O+ accounting for the largest inventory on hand. The data also shows that shortages occur exclusively in Rh negative types, with most shortages observed in B- followed by A-. However, wastage is distributed across all types, with O- followed by O+, accounting for the highest amounts of wastage. The relatively high wastage rate in O, the universal type, demonstrates the reliance of Ottawa area hospitals, especially small remote ones in the periphery, on compatible types to fill a significant proportion of their inventory. Emergency orders are also distributed among all types (both Rh negative and positive), with B+ emergency orders accounting for the highest number of emergency orders.

In the new scenario, trigger and order up to points for any newly added types are based on the average mean days on hand for A and O types, which are then used to calculate (s, S) levels for the newly added types. (s, S) levels for A and O types are only altered if their fractions have changed in the new scenario.

After switching to the new policy, the overall wastage rate in the Ottawa system rose to 3% of average daily demand. Average shortages also increase to 0.08% of demand. However, the hospital emergency order rate drops to 0.46% of demand.

Across all metrics, except for A- shortage rate, the changes from the baseline scenario are statistically significant. With the null hypothesis of equal means, at 5% alpha level, the tests, comparing the baseline scenario metrics against the new scenario metrics, are mostly rejected. See Table 33 to Table 36 for statistical tests of comparing the baseline metrics against the new scenario metrics.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	100.27	68.99	44.67	32.14	0.00
A+	547.91	1308.68	136.24	99.78	0.00
AB-	20.01	2.64	11.93	0.45	0.00
AB+	191.7	22.78	6.05	11.28	0.00
B-	34.15	2.98	23.43	0.96	0.00
B+	390.02	182.00	13.71	42.62	0.00
O-	128.70	36.34	88.80	21.03	0.00
O+	735.41	505.35	147.66	91.55	0.00

Table 33- Statistical test to compare the baseline supplier inventory mean against the new scenario supplier inventory mean in the Ottawa centre. All results are statistically significant at the $\alpha = 5\%$ level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.08	0.42	0.02	0.06	0.00
A+	0.12	1.83	0.04	0.18	0.00
AB-	0.06	0.35	0.04	0.04	0.00
AB+	0.00	0.62	0.00	0.07	0.00
B-	0.05	0.42	0.04	0.05	0.00
B+	0.07	0.73	0.02	0.08	0.00
O-	0.38	0.28	0.08	0.08	0.00
O+	0.32	2.46	0.04	0.04	0.00

Table 34- Statistical test to compare the baseline hospital wastage mean against the new scenario hospital wastage mean in the Ottawa centre All results are statistically significant at the $\alpha = 5\%$ level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.04	0.02	0.10	0.02	0.30
A+	0.00	0.00	0.00	0.00	0.00
AB-	0.04	0.00	0.05	0.00	0.00
AB+	0.00	0.00	0.00	0.00	0.00
B-	0.05	0.00	0.06	0.00	0.00
B+	0.00	0.00	0.00	0.00	0.00
O-	0.01	0.16	0.02	0.10	0.00
O+	0.00	0.00	0.00	0.00	0.00

Table 35- Statistical test to compare the baseline hospital shortage mean against the new scenario hospital shortage mean in the Ottawa centre. All values are significantly different except in instances where the p-value (highlighted) is above 0.05.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.56	0.26	0.11	0.15	0.00
A+	0.56	0.11	0.03	0.02	0.00
AB-	0.15	0.01	0.06	0.01	0.00
AB+	0.64	0.00	0.04	0.00	0.00
B-	0.41	0.06	0.04	0.05	0.00
B+	0.77	0.02	0.05	0.01	0.00
O-	0.19	0.55	0.03	0.44	0.00
O+	0.39	0.08	0.05	0.02	0.00

Table 36- Statistical test to compare the baseline hospital emergency order mean against the new scenario hospital emergency order mean in the Ottawa centre. All values are statistically significant at the $\alpha = 5\%$ level.

As can be seen in Table 33 to Table 36, the effect on the various metrics is not identical across all types. There is a reduction in supplier inventory level for all types, except for A+. Hospital wastage, however, increases for all types except for O-. Unlike the Newfoundland centre in which system-wide wastage decreases in the new scenario, in the Ottawa centre system-wide wastage increases. This increase occurs, despite the fact that AB+ and B+ wastage decrease in the new scenario. The system-wide wastage in all the other types closely resembles hospital wastage in the new scenario. The impact of the new scenario is again most apparent in the O- shortage level, which increases significantly. Shortages decrease for the remainder of the Rh negative types; no shortages are seen across any of Rh positive types. Hospital emergency orders closely follow shortages after the switch from the baseline to

the new scenario: O- emergency orders rise considerably in the new scenario, while the emergency orders decrease for all the other types. However, there is still a small number of emergency orders in the new scenario for all the types, including Rh positive types. One sided t-tests, were used to confirm that decreases or increases in the metrics of interest for all types, with the exception of A- shortage, are statistically significant. See Appendix F for one-sided t-tests of comparing the baseline metrics against the new scenario metrics.

To determine by how much O- collection needs to be raised over the population percentage (historically 7%) to ensure zero shortages, collection rates were varied systematically from 0.1% to 0.7% by 0.1%. The results show that shortages are mostly observed in A-, B- and O- types. However, increasing daily collections by 0.7%, would result in zero hospital shortages for all types. See Figure 21.

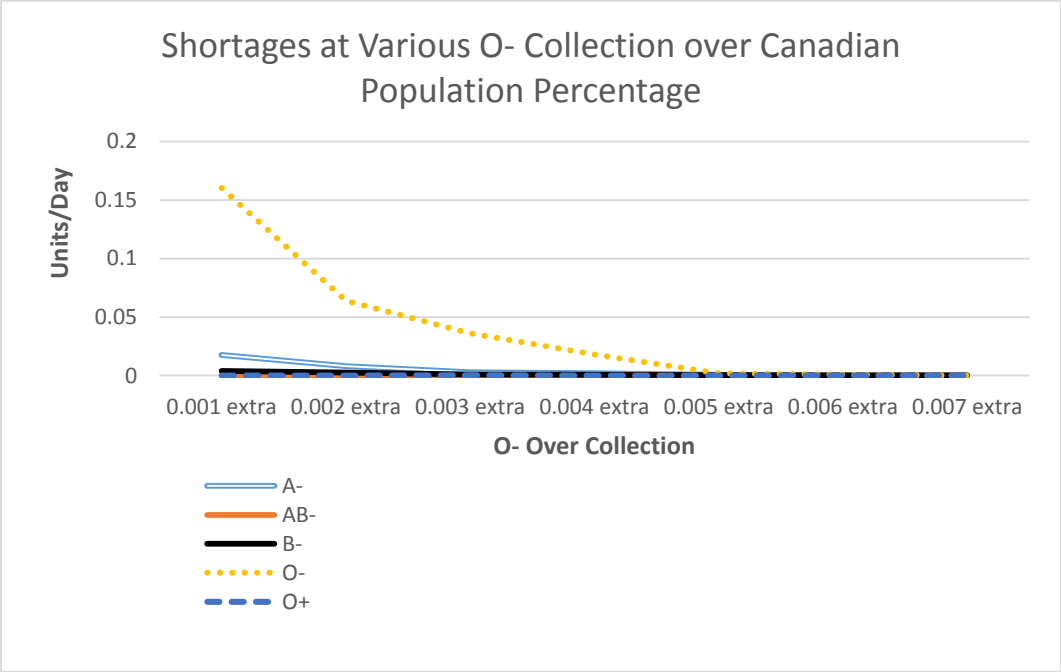

Figure 21- Shortages recorded at various O- collection over population distribution in the Ottawa centre.

However, by over collecting O- by 0.7% over the 7% level seen in the Canadian population distribution, hospital wastage would increase from 0.46% of average daily demand to 3.17%of average daily demand.

After multiplying the O- Canadian population percentage by 1.007, and then normalizing the resulting distribution, the new collection distribution is obtained. The new distribution is listed in Table 37.

Type	Canadian Population Percentages	Scenario Collection	Normalized Percentages	Historic Percentages
A-	6.00%	6.00%	6.00%	7.10%
A+	36.00%	36.00%	35.98%	29.30%
AB-	0.50%	0.50%	0.50%	0.70%
AB+	2.50%	2.50%	2.50%	2.80%
B-	1.40%	1.40%	1.40%	2.10%
B+	7.60%	7.60%	7.60%	8.60%
O-	7.00%	7.05%	7.05%	12.30%
O+	39.00%	39.00%	38.98%	37.00%
Total	100.00%	100.10%	100.00%	100.00%

Table 37- New collection percentages after increasing O- collection to achieve zero shortages for all types versus Canadian population percentages for the Ottawa centre

As can be observed in Table 37, by switching to the new scenario and collecting O- by 0.7% over its Canadian population percentage, O- collection decreases from 12.3% in historic dataset, to 7.05%.

BC and Yukon Centre Results

To create the baseline scenario for the BC and Yukon centre, the same underlying assumptions as in the Newfoundland centre were adopted. However, to account for FIFO violations occurring in the distribution of over collected types, namely AB+ and B+, two new cut-off points are selected. The cut-off point for AB+ is 18 days until expiry, while this cut off-point for B+ is set at 29 days until expiry. Unlike the Newfoundland centre, the historic distribution for imports is used without any modifications.

As in the case of the Newfoundland centre, the baseline scenario in the BC and Yukon centre was run for 30 replications of 364 days following a warm-up period of 42 days. The daily average metrics for supplier inventory level and hospital wastage, shortage and emergency order rates were similarly recorded for all blood types.

An overall wastage rate of 0.66% of average daily demand was observed across all hospitals in the BC and Yukon area. The overall shortage rate was recorded at 0.6% of demand; hospitals placed emergency orders at a rate equal to 0.9% of demand.

The data shows that Rh positive types have greater inventory levels at the supplier in the new scenario due to the higher prevalence of these blood types in the population, with O+ followed by A+ accounting for the largest inventory on hand. The data also shows that shortages exclusively occur among Rh negative types, with AB- followed by B-, accounting for the highest number of shortages. However, wastage is distributed across all types, with A+ accounting for the highest wastage. Emergency orders are also distributed among all types, with O+ accounting for the highest amount of emergency orders.

In the new scenario, trigger and order up to points for any newly added types are based on the maximum mean days on hand for A and O types, which are then used to recalculate new (s, S) for any newly added types. As in Newfoundland and Ottawa, (s, S) levels for A and O types are only altered if their fractions changed in the new scenario.

After switching to the new policy, the overall wastage rate rises to 1.02% of average daily demand, while the average shortage increases to 0.11% of the demand; hospitals placed more emergency orders in the new scenario, issuing emergency orders at a rate equal to 1.11% of demand.

With the null hypothesis of equal means, at 5% alpha level, the tests, comparing the baseline scenario metrics against the new scenario metrics, are mostly rejected. See Table 38 to Table 41 for statistical tests of comparing the baseline metrics against the new scenario metrics.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	114.65	43.66	57.19	29.07	0.00
A+	743.98	1208.14	140.96	149.07	0.00
AB-	13.79	3.25	10.65	0.64	0.00
AB+	180.86	44.09	42.58	16.61	0.00
B-	26.48	6.65	16.28	2.78	0.00
B+	332.69	85.28	57.06	21.22	0.00
O-	241.67	72.68	98.74	36.41	0.00
O+	1324.99	1518.29	149.96	126.26	0.00

Table 38- Statistical test to compare the baseline supplier inventory mean against the new scenario supplier inventory mean in the BC and Yukon centre. All results are statistically significant at the α = 5% level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.30	0.66	0.09	0.10	0.00
A+	0.73	1.28	0.08	0.10	0.00
AB-	0.18	0.41	0.08	0.06	0.00
AB+	0.45	0.65	0.13	0.13	0.00
B-	0.29	0.38	0.08	0.09	0.00
B+	0.25	0.26	0.03	0.06	0.30
O-	0.17	0.13	0.09	0.05	0.07
O+	0.10	0.04	0.03	0.02	0.00

Table 39- Statistical test to compare the baseline hospital wastage mean against the new scenario supplier hospital wastage in the BC and Yukon centre. All values are significantly different except in instances where the p-value (highlighted) is above 0.05.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.04	0.05	0.07	0.03	0.60
A+	0.00	0.00	0.00	0.00	0.00
AB-	0.1	0.00	0.06	0.00	0.00
AB+	0.00	0.00	0.00	0.00	0.00
B-	0.07	0.01	0.07	0.01	0.00
B+	0.00	0.00	0.00	0.00	0.00
O-	0.00	0.33	0.02	0.22	0.00

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
O+	0.00	0.00	0.00	0.00	0.00

Table 40- Statistical test to compare the baseline hospital shortage mean against the new scenario hospital shortage mean in the BC and Yukon centre. All values are significantly different except in instances where the p-value (highlighted) is above 0.05.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.24	0.38	0.13	0.14	0.00
A+	0.55	0.70	0.05	0.03	0.00
AB-	0.38	0.02	0.17	0.01	0.00
AB+	0.32	0.05	0.04	0.01	0.00
B-	0.27	0.18	0.25	0.07	0.05
B+	0.14	0.19	0.02	0.03	0.00
O-	0.52	1.13	0.04	0.39	0.00
O+	0.93	1.52	0.07	0.09	0.00

Table 41- Statistical test to compare the baseline hospital emergency order mean against the new scenario hospital emergency order mean in the BC and Yukon centre. All values are significantly different except in instances where the p-value (highlighted) is above 0.05.

As can be seen in Table 38 to Table 41, the effect on various metrics is not uniform across all types. Supplier inventory decreases for all types, except O+ and A+. Hospital wastage also increases for all types, except for O- and O+. Like the Newfoundland center, system-wide wastage decreases in the new scenario. However, this decrease in system-wide wastage is mainly due to the decrease in wastage of B+ in the new scenario and not AB+. The system-wide wastage across all the other types, closely resembles the hospital wastage, in the new scenario. The impact on shortages in the new scenario is most apparent in O-, which increases dramatically in the new scenario. Shortages go down for AB- and B-, but go up for A-. No shortage was observed across any of Rh positive types. Hospital emergency orders again were observed to closely follow shortages after the switch from the baseline to the new scenario; emergency order rates go down for AB- and B- but increase for A- and O-. Emergency orders were also observed to increase for all Rh positive types except for AB+. One sided t-tests were used to confirm that decrease or increase in the metrics of interest for all types, with the exception of A- shortage rate increase, B+ wastage rate increases and O- wastage rate decreases, are statistically

significant. See Appendix F for one-sided t-tests of comparing the baseline metrics against the new scenario metrics.

To determine by how much O- collection needs to be raised over its population percentage of 7%, to ensure zero shortages, collection rates were varied systematically from 0.1% to 0.7% by 0.1%. Results of these experiments show that shortages are mostly observed in A-, B- and O- types. However, increasing daily collections by 0.7%, would result in zero hospital shortages for all types.

For a plot of shortage rates at various O- collection over 7% see Figure 22.

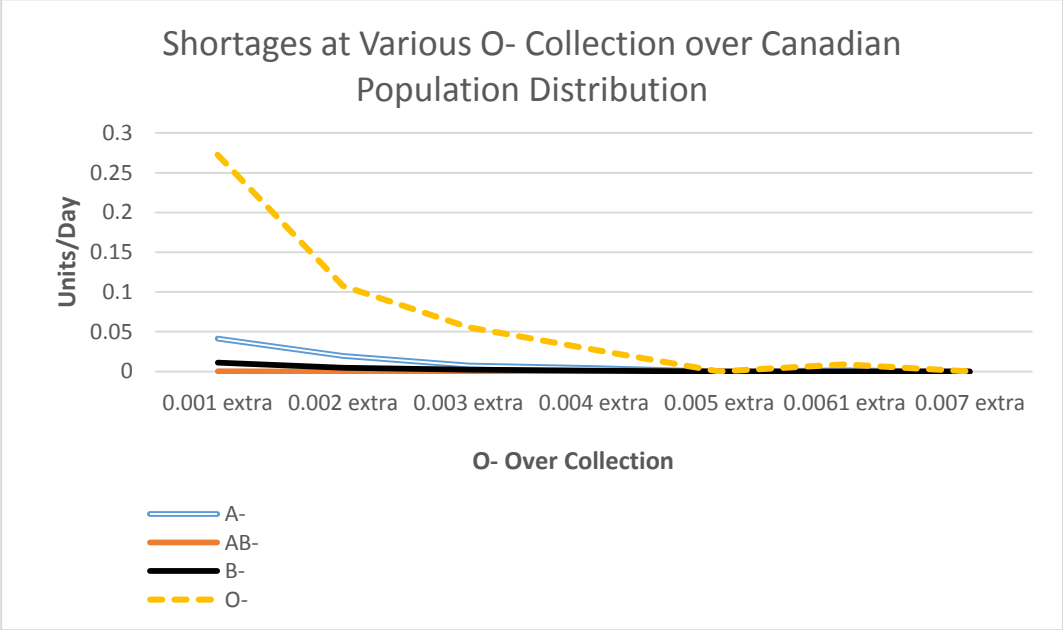

Figure 22- Shortages recorded at various O- collection over population distribution in the BC and Yukon centre

However, by over collecting O- by 0.7% over the 7% level seen in the Canadian population distribution, hospital wastage increases from 0.66% of average daily demand to 1.12% of average daily demand.

After multiplying the O- Canadian population percentage by 1.007, and then normalizing the resulting distribution, the new collection distribution is obtained. The new percentages are listed in Table 42.

Type	Canadian Population Percentages	Scenario Collection	Normalized Percentages	Historic Percentages
A-	6.00%	6.00%	6.00%	7.00%
A+	36.00%	36.00%	35.98%	29.00%
AB-	0.50%	0.50%	0.50%	1.00%
AB+	2.50%	2.50%	2.50%	3.00%
B-	1.40%	1.40%	1.40%	2.00%
B+	7.60%	7.60%	7.60%	11.00%
O-	7.00%	7.05%	7.05%	11.00%
O+	39.00%	39.00%	38.98%	36.00%
Total	100.00%	100.10%	100.00%	100.00%

Table 42- New collection percentages after increasing O- collection to achieve zero shortages for all types versus Canadian population percentages for the BC and Yukon centre

As can be observed in Table 42, by switching to the new scenario and collecting O- by 0.7% over its Canadian population percentage, O- collection decreases from 11% in historic dataset, to 7.05%.

Summary

Uniform Changes across the Three Centres

Switching from the baseline scenario that over orders universal types to a policy that matches the blood type distribution within the Canadian population would lead to a healthier and less overstocked inventory in all three centres. A decline in inventory level is observed in all types, except for A+ and O+ (with the exception of the medium centre), which are the most prevalent types in the population. This decrease in inventory at all suppliers is achieved at the cost of more hospital wastage. Wastage was observed to increase across less universal types of AB and B, which were not ordered in the baseline scenario, as well as A+, across all three centres. Shortages were observed to occur in the Rh negative types in all centres under the new scenario. Reducing collections of O-, as the most

transfusable type, however, was observed to result in an increase in emergency orders and shortages for this type. Therefore, to achieve zero shortage rates for all types, O- collection must be increased over Canadian population percentage of 7% by a certain amount. In Newfoundland and Labrador, a small centre, this amount was found to be around 1.4%. For the medium centre of Ottawa and large centre of BC and Yukon, this amount was estimated at around 0.7%.

Comparing the Three Centres in Terms of Overall Results

Switching from the baseline scenario to the new scenario would lead to a wastage increase in hospitals, in all three centres. The hospital shortage rate also increases for the medium and large centre, but stays at about the same rate at the small centre. The rate at which hospitals place emergency orders was observed to decrease at the small and the medium centre, but to increase at the large centre.

Comparing the Three Centres in Terms of Results by Type

For a comparison of changes from the baseline scenario to the new scenario, for all the metrics in all three centres, see Table 43 to Table 46. The arrows represent either an upward or a downward trend for each metric/type. Blank cells represent metrics with no change.

		Change from the baseline to the new scenario		
Metric	Type	Centre		
Supplier inventory		Small	Medium	Large
	A-	↓	↓	↓
	A+	↑	↑	↑
	AB-	↓	↓	↓
	AB+	↓	↓	↓
	B-	↓	↓	↓
	B+	↓	↓	↓
	O-	↓	↓	↓
	O+	↑	↓	↑

Table 43- Comparison of supplier inventory by type from the baseline to the new scenario, in small, medium and large centre

		Change from the baseline to the new scenario		
Metric	Type	Centre		
Hospital wastage		Small	Medium	Large
	A-	↓	↑	↑
	A+	↑	↑	↑
	AB-	No change	↑	↑
	AB+	↑	↑	↑
	B-	↑	↑	↑
	B+	↑	↑	↑
	O-	↑	↓	↓
	O+	↑	↑	↓

Table 44- Comparison of hospital wastage by type from the baseline to the new scenario, in small, medium and large centre

		Change from the baseline to the new scenario		
Metric	Type	Centre		
Hospital shortage		Small	Medium	Large
	A-	↓	↓	↑
	A+	↓		
	AB-	↓	↓	↓
	AB+			
	B-	↓	↓	↓
	B+			
	O-	↑	↑	↑
	O+	↓		

Table 45- Comparison of hospital shortage by type from the baseline to the new scenario, in small, medium and large centre

		Change from the baseline to the new scenario		
Metric	Type	Centre		
Hospital emergency orders		Small	Medium	Large
	A-	↓	↓	↑
	A+	↓	↓	↑
	AB-	↓	↓	↓
	AB+	↓	↓	↓
	B-	↓	↓	↓
	B+	↓	↓	↑
	O-	↑	↑	↑
	O+	↓	↓	↑

Table 46- Comparison of hospital emergency order by type from the baseline to the new scenario, in small, medium and large centre

As may be seen from the tables, switching from the baseline scenario to the new scenario leads to reduced inventory for all types, in all the centres, except for A+ and O+. The only exception is O+ supplier inventory, at the medium centre, which was observed to decrease, in the new scenario.

The change from the baseline scenario to the new scenario results in an increased wastage rate for non-universal types, in all the centres, with the exception of AB- in the small centre which stays at the same rate. The wastage rate for A+ also increases in all three centres. An increase in O+ wastage rate, another common type, was witnessed at the small and medium centre. However, the wastage rate for O+ decreases at the large centre. The A- wastage rate increases in the medium and large centres, but drops in the small centre. Finally, the O- wastage rate decreases in the medium and large centres, but increases in the small centre.

With regard to shortages, the most noticeable change from the baseline to the new scenario is the increase in the O- shortage rate. For all the other types, the shortage rate declines from the baseline scenario, in all the centres, excluding the shortage rate of A- in the large centre that increases in the new scenario.

The most apparent change in emergency orders from the baseline scenario to the new scenario is the increase in the emergency order rates for O- type. When switching from the baseline to the new scenario, emergency order rates were observed to decrease for all the other types, in the small and medium centres. However, emergency orders go up in all the Rh positive types, as well as A-, in the large centre.

Chapter 5 Conclusion and Future Research

It is common practice in many hospital blood banks to overstock their inventory with type O blood, since it is universally transfusable, and A type blood, since it is in common demand. This practice allows hospitals to cover demand for all types, including less universal types of AB and B, while protecting against high wastage of less universal or lower demand types. Consequently, blood suppliers are forced to over collect O and A types, especially O-.

In this study we employ a discrete event simulation method, developed in Microsoft Visual Basic.Net, to evaluate blood ordering policies in a small regional blood collection and distribution centre, Newfoundland and Labrador, and the hospitals within its catchment area. The simulation model employed in this study is based on a framework developed by Blake and Hardy (2014). The model for this study was verified and validated against the Newfoundland and Labrador data set, which covers the period between 01 April 2011 and 31 March 2012. The model, once tested and validated, was later ported to represent a medium and a large CBS distribution network in Ottawa and in BC and Yukon.

In our study, the model was modified such that the distribution of blood types observed in collection, imports, demand and exports were equivalent to that of the Canadian population. Four metrics of interest, supplier inventory, hospital shortage, wastage and emergency order rates, were used to evaluate the change from the baseline to the new scenario.

Results show that switching ordering policies from the existing framework to a policy that matches the blood type distribution within the Canadian population, would lead to a healthier and less overstocked inventory in all three centres. A decline in inventory level was observed in all types, except for A+ and O+. The reduced inventory, especially in Rh negative types, occurs because types B and AB are used in the new scenario to fill demand, instead of substituting a compatible unit. However, this decrease in inventory at suppliers is achieved at the cost of more hospital wastage. Wastage was observed to generally increase across the less universal types of AB and B, which were not ordered in

the baseline scenario, as well as A+. The most noticeable change in shortage from the baseline to the new scenarios was in O-, which was caused by reducing the collections for this type. For all the other types, the shortage rate goes down from the baseline scenario, in all the centres, excluding the shortage rate of A- in the large centre that increases in the new scenario. The most substantial change in emergency orders occurred in the O- emergency order rate, which was consistent with the increased shortages of this type in the new scenario.

Since reducing collections of O- was also observed to result in an increase in emergency orders and shortages, the model was used to show that O- collection must exceed the Canadian population percentage of around 7%, by some amount, to achieve zero shortages. In the small centre, this amount was found to be around 1.4%. For the medium and large centres, this amount was estimated at 0.7%. Therefore, our study suggests that a reduction in O- collections to between 1% to 2% in excess of the rate in the Canadian population is possible and would result in very low RBC shortage, so long as hospitals stocked inventory at rates approximately equal to the distribution of blood types within the Canadian population.

However, our experience also suggests that a change of ordering policy is more difficult to implement in smaller hospitals. In our study, order policies were calculated on the basis of expected daily demand between reorder points. When demand is very small, reorder points and target inventory may both be calculated as zero under the new policy. Thus a shift to a collection and ordering policy equivalent to that of the distribution of blood types within the Canadian population may not greatly increase the amount of AB and B type blood that is stocked. Therefore, for the policy to be more efficient in small centers, or in small or remote hospitals, it may be advantageous to carry a small reserve of B type. Requiring small or remote hospitals to carry an extra B type reserve would undoubtedly lead to more wastage. However, this wastage increase might be mitigated by the healthier inventory level for more compatible types, especially type O-. We suggest that future work be directed

towards the question of benefit of requiring a minimum level of B type blood at small or remote hospitals. Moreover, through a more focused study on the size of hospitals, another policy could be proposed that would specifically address hospitals with a medium sized demand.

Another proviso for our proposed new policy, revolves around collection of AB+. Currently, AB+ units are collected, at a rate exceeding their RBC usage, to obtain plasma; collecting AB+ at rates normalized to population means might not be feasible, since over collection is necessary to meet the requirements for other products.

The simulation model used in this study has potential for further development. By running the model in a network of other suppliers (possibly all the regional centres across the country) and adopting a dynamic import and export policy, it could be used to investigate rebalancing inventory between centres. Such a study would be essential when switching collections and demand to Canadian population distribution on a system wide basis. There is also the potential to combine the model with exact or heuristic methods to search for optimal inventory policies at both suppliers and hospitals. For instance, instead of using the conventional (s, S) used by hospitals, the re-order and order up to points could be optimized across all blood types. Such a study could also be extended to determine the optimal shortage and wastage rates, both for single supply chains as well as for a network of regional networks.

Our results show that switching to an ordering policy normalized to population means is feasible, but at the risk of more wastage at hospitals. Therefore, a study explicitly considering costs should be completed. The study should establish the trade-off between increased product wastage and reduced recruiting efforts for O- donors. Finally, we suggest that a study be conducted to evaluate the use of differentially costing products, either as a per unit price or as a function of determining provincial share of the CBS budget, as a mechanism for supporting an ordering policy normalized to the Canadian population.

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Appendix A: Supplier Object Properties and Methods

Property	Parameters	Description
MyName		Text name of object instance
Wastage	{intType}	The number of units wasted today, or the number of units wasted in blood group *intType*, if specified
Shortage	{intType}	The number of units demand not filled today, or the number of units not filled in blood group *intType* if specified
Inventory	intAge, {intType}	The total number of units with age *intAge* days remaining shelf life in inventory, or the total number of units with age *intAge* remaining of blood type *intType* remaining if specified
Arrivals	{intType}	The total number of units arriving today, or the total number of units of type *intType* if specified
Demand	{intType}	The total number of units demanded today, or the total units demanded of type *intType* if specified
AgeUsed	{intType}	The average age of outgoing stock, or the average age of outgoing stock of type *intType* if specified
Imports	{intType}	The number of units imported today, or the total number of units imported of type *intType* if specified
Exports	{intType}	The number of units exported today, or the total number of units exported of type *intType* if specified
EmergencyFilled	{intType}	The total number of units to fill emergency demand, or the units required to fill emergency demand of type *intType* if specified
ArrivalTarget	intDay	The average expected units to arrive from testing on *intDay* of the week (supplier) or the average expected demand on intDay of week
ArrivalAge	intDay, intAge	The probability that a unit arriving from testing on *intDay* of the week has a remaining shelf life of *intAge* days
ImportTarget	intDay	The average number of units to import on day *intDay*
ImportType	intType	The probability a unit imported is of type *intType*
ImportAge	intDay, intAge	The probability that a unit imported on day of the week *intDay* is of age *intAge*
ExportTarget	intDay	The average number of units to be exported on day of week *intDay*
ExportType	intType	The probability a unit exported is of type *intType*
TypeMatch	intPType, intDType	The number of emergency order units filled with compatible units of type *intDType* in response to demand of type *intPType*

Table A1- Supplier object properties (Blake & Hardy, 2014)

Method	Description
InitializeInventory	Causes the inventory at the supplier to be initialized at the start of the simulation run. The routine sums the total expected demand from all hospitals and brings this number of units into inventory (units are assumed to have a randomly assigned remaining shelf life). Inventory is initialized so that all hospitals start the simulation with their desired inventory level.
AdvanceInventory	Causes stock on hand to age by one day. Stock with remaining shelf life of -1 days is outdated.
ArriveInventory	Causes units to arrive at the supplier site from testing. Arrivals are assumed to be Poisson distributed with a mean arrival rate specific to day of week. The mean arrivals may, however, be adjusted up or down if a 7-day moving average is below or above a target inventory. Using the adjusted mean arrival rate, a random number of units is generated. These units are assigned a blood type from an empirical distribution and a remaining shelf-life, again drawn from an empirical distribution. The arriving inventory is then entered into inventory.
Import	Causes units to be imported from other supplier sites. The number of units to import is drawn from a Poisson distribution, specific to day of week. The units are assigned a blood group and type and are assigned a remaining shelf life (both values are drawn from empirical distributions) and are entered into inventory.
Export	Causes units to be exported to other distribution centres. The number of units of demand for exports is drawn from a Poisson distribution, specific to day of week. The demand units are assigned a blood group and type, drawn from an empirical distribution, and if units are available are removed into inventory.
FillOrder	Calculates the total demand for units of each blood type and determines if there is sufficient inventory to fill all demand. If there is not, FillOrder returns a scaling factor used to adjust hospital demand to meet available inventory.
TransferInventory	Removes units from inventory and enters them into a temporary array to be passed to the hospital in response to daily demand.
EmergencyOrder	Causes units to be withdrawn from inventory and transferred to the hospital in response to emergency orders.
CheckTypeMatch	Checks for compatible units in the event that insufficient stock is available to fill emergency orders.
DoTypeMatch	Causes compatible units identified by CheckTypeMatch to be withdrawn from inventory and transferred to the hospital.
CollectStatistics	Collates statistics for today and then clears the statistical counters.

Table A2- Supplier object methods (Blake & Hardy, 2014)

Appendix B: Hospital Object Properties and Methods

Property	Parameters	Description
MyName		Text name of object instance
Wastage	{intType}	The number of units wasted today, or the number of units wasted in blood group *intType*, if specified
Shortage	{intType}	The number of units demand not filled today, or the number of units not filled in blood group *intType* if specified
Inventory	intAge, {intType}	The total number of units with age *intAge* days remaining shelf life in inventory, or the total number of units with age *intAge* remaining of blood type *intType* remaining if specified
Demand	{intType}	The total number of units demanded today, or the total units demanded of type *intType* if specified
AgeUsed	{intType}	The average age of transfused stock, or the average age of transfused stock of type *intType* if specified
ArrivalTarget	intDay	The average expected demand on intDay of week
EmergDemand	{intType}	The number of units ordered on an emergency basis today, or the number of units ordered on an emergency basis of type *intType* if specified
EmergencyFilled	{intType}	The number of units received today, or the number of units received of type *intType* if specified
TypeMatch	intPType, intDType	The number of units of demand for type *intPType* which are filled with units of the compatible type *intDType*

Table B1- Hospital object properties (Blake & Hardy, 2014)

Method	Description
AdvanceInventory	Causes stock on hand to age by one day. Stock with remaining shelf life of -1 days is outdated.
OrderInventory	Causes a request for inventory replenishment to be issued to the supplier. Hospitals observe their inventory on a blood-type by blood-type basis. The current inventory is compared against a hospital specific inventory trigger. If inventory is below this level, an order is generated to return inventory to a hospital specific inventory target. To minimize orders, it is assumed that if any blood type requires replenishment, orders are issued to return all blood types to their order up to level.
ReceiveInventory	Causes units to be withdrawn from the supplier and entered into the hospital's inventory. Units are entered into the hospital's inventory according to blood type and remaining shelf life.
GenerateDemand	Causes demand for product to be generated. A random variable is drawn to determine if any demand will be observed on this day of the week. If so, a second random variate is generated from a Poisson distribution specific to day of week to determine the total number of

	units to be transfused. The blood type is then determined for each demand request by sampling from a hospital specific empirical distribution. Requests are then filled, FIFO, from available inventory. Type matching for compatible units may or may not be allowed (this is an optional parameter in the model). Any demand that cannot be satisfied with stock available on the shelf generates an emergency order to the supplier.
ReceiveEmergOrder	Counts units received from the supplier as part of an emergency order
CheckTypeMatch	Checks for compatible units in the event that insufficient stock is available to fill demand.
DoTypeMatch	Causes compatible units identified by *CheckTypeMatch* to be withdrawn from inventory and transfused.
CollectStatistics	Collates statistics for today and then clears the statistical counters.

Table B2- Hospital object methods (Blake & Hardy, 2014)

Appendix C: List of Historic versus New (s, S) for each Hospital and each Blood Type in all Centres

Hospital Name	Type	Historic s	Historic S	New s	New S
BONAVISTA PENINSULA COMMUNITY HLTH CARE	A-	1	2	0	1
BONAVISTA PENINSULA COMMUNITY HLTH CARE	A+	0	2	1	2
BONAVISTA PENINSULA COMMUNITY HLTH CARE	AB-	0	0	0	1
BONAVISTA PENINSULA COMMUNITY HLTH CARE	AB+	0	0	0	1
BONAVISTA PENINSULA COMMUNITY HLTH CARE	B-	0	0	0	1
BONAVISTA PENINSULA COMMUNITY HLTH CARE	B+	0	0	1	2
BONAVISTA PENINSULA COMMUNITY HLTH CARE	O-	1	2	0	1
BONAVISTA PENINSULA COMMUNITY HLTH CARE	O+	1	2	1	3
BURIN PENINSULA HEALTH CARE CENTRE	A-	1	2	0	1
BURIN PENINSULA HEALTH CARE CENTRE	A+	2	4	3	5
BURIN PENINSULA HEALTH CARE CENTRE	AB-	0	0	0	1
BURIN PENINSULA HEALTH CARE CENTRE	AB+	0	0	0	1
BURIN PENINSULA HEALTH CARE CENTRE	B-	0	0	0	1
BURIN PENINSULA HEALTH CARE CENTRE	B+	0	0	1	3
BURIN PENINSULA HEALTH CARE CENTRE	O-	4	6	1	2
BURIN PENINSULA HEALTH CARE CENTRE	O+	4	6	5	7
CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	A-	5	6	3	4
CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	A+	4	6	7	9
CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	AB-	0	0	0	1
CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	AB+	0	0	0	1
CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	B-	0	0	0	1
CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	B+	0	0	1	3
CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	O-	4	6	1	2
CAPTAIN WILLIAM JACKMAN MEMORIAL HOSP	O+	7	10	10	12
CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	A-	8	10	5	6
CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	A+	14	18	19	21
CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	AB-	0	0	0	1
CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	AB+	0	0	2	3
CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	B-	0	0	1	2
CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	B+	0	0	6	7
CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	O-	8	10	4	5
CENTRAL NEWFOUNDLAND REGIONAL HLTH CTR	O+	13	18	15	18
DR. CHARLES LEGROW HEALTH CENTRE	A-	0	2	0	1
DR. CHARLES LEGROW HEALTH CENTRE	A+	1	4	3	5
DR. CHARLES LEGROW HEALTH CENTRE	AB-	0	0	0	1

Hospital Name	Type	Historics	HistoricS	News	NewS
DR. CHARLES LEGROW HEALTH CENTRE	AB+	0	0	0	1
DR. CHARLES LEGROW HEALTH CENTRE	B-	0	0	0	1
DR. CHARLES LEGROW HEALTH CENTRE	B+	0	0	0	2
DR. CHARLES LEGROW HEALTH CENTRE	O-	0	2	0	1
DR. CHARLES LEGROW HEALTH CENTRE	O+	1	4	3	5
BAIE VERTE PENINSULA HEALTH CARE	A-	0	0	0	0
BAIE VERTE PENINSULA HEALTH CARE	A+	0	0	0	0
BAIE VERTE PENINSULA HEALTH CARE	AB-	0	0	0	0
BAIE VERTE PENINSULA HEALTH CARE	AB+	0	0	0	0
BAIE VERTE PENINSULA HEALTH CARE	B-	0	0	0	0
BAIE VERTE PENINSULA HEALTH CARE	B+	0	0	0	0
BAIE VERTE PENINSULA HEALTH CARE	O-	0	0	0	0
BAIE VERTE PENINSULA HEALTH CARE	O+	0	0	0	0
CARBONEAR GENERAL HOSPITAL	A-	3	4	1	2
CARBONEAR GENERAL HOSPITAL	A+	4	6	6	8
CARBONEAR GENERAL HOSPITAL	AB-	0	0	0	1
CARBONEAR GENERAL HOSPITAL	AB+	0	0	0	1
CARBONEAR GENERAL HOSPITAL	B-	0	0	0	1
CARBONEAR GENERAL HOSPITAL	B+	0	0	2	3
CARBONEAR GENERAL HOSPITAL	O-	3	4	1	2
CARBONEAR GENERAL HOSPITAL	O+	3	6	5	7
DR G B CROSS MEMORIAL HOSPITAL	A-	1	2	1	2
DR G B CROSS MEMORIAL HOSPITAL	A+	4	6	7	9
DR G B CROSS MEMORIAL HOSPITAL	AB-	0	0	0	1
DR G B CROSS MEMORIAL HOSPITAL	AB+	0	0	0	1
DR G B CROSS MEMORIAL HOSPITAL	B-	0	0	0	1
DR G B CROSS MEMORIAL HOSPITAL	B+	0	0	1	3
DR G B CROSS MEMORIAL HOSPITAL	O-	5	6	1	2
DR G B CROSS MEMORIAL HOSPITAL	O+	8	10	8	10
GRENFELL REGIONAL HEALTH SERVICES	A-	5	6	4	6
GRENFELL REGIONAL HEALTH SERVICES	A+	10	12	16	18
GRENFELL REGIONAL HEALTH SERVICES	AB-	0	0	0	1
GRENFELL REGIONAL HEALTH SERVICES	AB+	0	0	0	1
GRENFELL REGIONAL HEALTH SERVICES	B-	0	0	0	1
GRENFELL REGIONAL HEALTH SERVICES	B+	0	0	2	3
GRENFELL REGIONAL HEALTH SERVICES	O-	3	6	1	2
GRENFELL REGIONAL HEALTH SERVICES	O+	8	12	10	12
JAMES PATON MEMORIAL HOSPITAL	A-	3	4	3	4
JAMES PATON MEMORIAL HOSPITAL	A+	9	13	16	19

Hospital Name	Type	Historics	HistoricS	News	NewS
JAMES PATON MEMORIAL HOSPITAL	AB-	0	0	0	1
JAMES PATON MEMORIAL HOSPITAL	AB+	0	0	1	2
JAMES PATON MEMORIAL HOSPITAL	B-	0	0	0	1
JAMES PATON MEMORIAL HOSPITAL	B+	0	0	3	5
JAMES PATON MEMORIAL HOSPITAL	O-	5	8	2	3
JAMES PATON MEMORIAL HOSPITAL	O+	7	13	9	12
LABRADOR HEALTH SERVICES BOARD	A-	0	0	1	2
LABRADOR HEALTH SERVICES BOARD	A+	4	6	7	9
LABRADOR HEALTH SERVICES BOARD	AB-	0	0	0	1
LABRADOR HEALTH SERVICES BOARD	AB+	0	0	0	1
LABRADOR HEALTH SERVICES BOARD	B-	0	0	0	1
LABRADOR HEALTH SERVICES BOARD	B+	0	0	1	2
LABRADOR HEALTH SERVICES BOARD	O-	4	6	1	2
LABRADOR HEALTH SERVICES BOARD	O+	3	6	3	5
PLACENTIA HEALTH CARE CENTRE	A-	1	2	0	1
PLACENTIA HEALTH CARE CENTRE	A+	3	4	4	6
PLACENTIA HEALTH CARE CENTRE	AB-	0	0	0	1
PLACENTIA HEALTH CARE CENTRE	AB+	0	0	0	1
PLACENTIA HEALTH CARE CENTRE	B-	0	0	0	1
PLACENTIA HEALTH CARE CENTRE	B+	0	0	1	2
PLACENTIA HEALTH CARE CENTRE	O-	1	2	0	1
PLACENTIA HEALTH CARE CENTRE	O+	3	4	4	6
SIR THOMAS RODDICK HOSPITAL	A-	5	6	3	4
SIR THOMAS RODDICK HOSPITAL	A+	8	10	10	12
SIR THOMAS RODDICK HOSPITAL	AB-	0	0	0	1
SIR THOMAS RODDICK HOSPITAL	AB+	0	0	1	2
SIR THOMAS RODDICK HOSPITAL	B-	0	0	0	1
SIR THOMAS RODDICK HOSPITAL	B+	0	0	3	4
SIR THOMAS RODDICK HOSPITAL	O-	7	8	3	4
SIR THOMAS RODDICK HOSPITAL	O+	8	10	9	11
HEALTH SCIENCES CENTRE	A-	7	10	6	7
HEALTH SCIENCES CENTRE	A+	22	30	32	36
HEALTH SCIENCES CENTRE	AB-	0	0	0	1
HEALTH SCIENCES CENTRE	AB+	1	2	2	3
HEALTH SCIENCES CENTRE	B-	1	1	1	2
HEALTH SCIENCES CENTRE	B+	2	4	8	9
HEALTH SCIENCES CENTRE	O-	8	12	5	6
HEALTH SCIENCES CENTRE	O+	21	30	27	31
ST. CLARE'S MERCY HOSPITAL	A-	2	4	1	3

Hospital Name	Type	Historic s	Historic S	New s	New S
ST. CLARE'S MERCY HOSPITAL	A+	7	12	9	12
ST. CLARE'S MERCY HOSPITAL	AB-	0	0	0	1
ST. CLARE'S MERCY HOSPITAL	AB+	1	2	0	1
ST. CLARE'S MERCY HOSPITAL	B-	0	0	0	1
ST. CLARE'S MERCY HOSPITAL	B+	3	4	2	4
ST. CLARE'S MERCY HOSPITAL	O-	2	4	1	3
ST. CLARE'S MERCY HOSPITAL	O+	7	12	11	14
WESTERN MEMORIAL HOSPITAL	A-	10	12	7	9
WESTERN MEMORIAL HOSPITAL	A+	27	30	43	46
WESTERN MEMORIAL HOSPITAL	AB-	1	2	0	1
WESTERN MEMORIAL HOSPITAL	AB+	1	2	3	4
WESTERN MEMORIAL HOSPITAL	B-	1	2	1	2
WESTERN MEMORIAL HOSPITAL	B+	5	6	9	11
WESTERN MEMORIAL HOSPITAL	O-	15	18	6	7
WESTERN MEMORIAL HOSPITAL	O+	25	30	28	31

Table C1- List of historic versus new (s, S) for all hospitals and types in Newfoundland and Labrador

Hospital Name	Type	Historic s	Historic S	New s	New S
ANSON GENERAL HOSPITAL- IROQUOIS FALLS	A-	0	0	0	0
ANSON GENERAL HOSPITAL- IROQUOIS FALLS	A+	0	0	0	0
ANSON GENERAL HOSPITAL- IROQUOIS FALLS	AB-	0	0	0	1
ANSON GENERAL HOSPITAL- IROQUOIS FALLS	AB+	0	0	0	1
ANSON GENERAL HOSPITAL- IROQUOIS FALLS	B-	0	0	0	1
ANSON GENERAL HOSPITAL- IROQUOIS FALLS	B+	0	0	0	1
ANSON GENERAL HOSPITAL- IROQUOIS FALLS	O-	1	2	0	1
ANSON GENERAL HOSPITAL- IROQUOIS FALLS	O+	1	4	2	4
BLIND RIVER DISTRICT HEALTH CENTRE	A-	0	0	0	0
BLIND RIVER DISTRICT HEALTH CENTRE	A+	1	4	3	5
BLIND RIVER DISTRICT HEALTH CENTRE	AB-	0	0	0	1
BLIND RIVER DISTRICT HEALTH CENTRE	AB+	0	0	0	1
BLIND RIVER DISTRICT HEALTH CENTRE	B-	0	0	0	1
BLIND RIVER DISTRICT HEALTH CENTRE	B+	0	0	0	1
BLIND RIVER DISTRICT HEALTH CENTRE	O-	2	4	0	2
BLIND RIVER DISTRICT HEALTH CENTRE	O+	1	4	3	5
CHAPLEAU HEALTH SERVICES	A-	0	0	0	1
CHAPLEAU HEALTH SERVICES	A+	0	0	2	4
CHAPLEAU HEALTH SERVICES	AB-	0	0	0	1
CHAPLEAU HEALTH SERVICES	AB+	0	0	0	1
CHAPLEAU HEALTH SERVICES	B-	0	0	0	1

Hospital Name	Type	Historics	HistoricS	News	NewS
CHAPLEAU HEALTH SERVICES	B+	0	0	0	1
CHAPLEAU HEALTH SERVICES	O-	2	5	0	1
CHAPLEAU HEALTH SERVICES	O+	1	5	2	4
ENGLEHART & DISTRICT HOSPITAL	A-	0	0	5	6
ENGLEHART & DISTRICT HOSPITAL	A+	0	0	31	32
ENGLEHART & DISTRICT HOSPITAL	AB-	0	0	0	1
ENGLEHART & DISTRICT HOSPITAL	AB+	0	0	2	3
ENGLEHART & DISTRICT HOSPITAL	B-	0	0	1	2
ENGLEHART & DISTRICT HOSPITAL	B+	0	0	6	7
ENGLEHART & DISTRICT HOSPITAL	O-	1	4	0	1
ENGLEHART & DISTRICT HOSPITAL	O+	3	4	66	68
ESPANOLA GENERAL HOSPITAL	A-	0	0	0	1
ESPANOLA GENERAL HOSPITAL	A+	2	2	1	3
ESPANOLA GENERAL HOSPITAL	AB-	0	0	0	1
ESPANOLA GENERAL HOSPITAL	AB+	0	0	0	1
ESPANOLA GENERAL HOSPITAL	B-	0	0	0	1
ESPANOLA GENERAL HOSPITAL	B+	0	0	0	1
ESPANOLA GENERAL HOSPITAL	O-	2	2	0	2
ESPANOLA GENERAL HOSPITAL	O+	2	6	3	5
HORNEPAYNE COMMUNITY HOSPITAL	A-	0	0	0	1
HORNEPAYNE COMMUNITY HOSPITAL	A+	1	2	1	2
HORNEPAYNE COMMUNITY HOSPITAL	AB-	0	0	0	1
HORNEPAYNE COMMUNITY HOSPITAL	AB+	0	0	0	1
HORNEPAYNE COMMUNITY HOSPITAL	B-	0	0	0	1
HORNEPAYNE COMMUNITY HOSPITAL	B+	0	0	0	1
HORNEPAYNE COMMUNITY HOSPITAL	O-	1	2	0	1
HORNEPAYNE COMMUNITY HOSPITAL	O+	1	2	2	3
KIRKLAND & DISTRICT HOSPITAL	A-	1	2	1	2
KIRKLAND & DISTRICT HOSPITAL	A+	2	6	6	7
KIRKLAND & DISTRICT HOSPITAL	AB-	0	0	0	1
KIRKLAND & DISTRICT HOSPITAL	AB+	0	0	0	1
KIRKLAND & DISTRICT HOSPITAL	B-	0	0	0	1
KIRKLAND & DISTRICT HOSPITAL	B+	0	0	1	2
KIRKLAND & DISTRICT HOSPITAL	O-	1	4	1	3
KIRKLAND & DISTRICT HOSPITAL	O+	6	10	7	9
LADY MINTO HOSPITAL - COCHRANE	A-	0	0	0	1
LADY MINTO HOSPITAL - COCHRANE	A+	0	0	0	0
LADY MINTO HOSPITAL - COCHRANE	AB-	0	0	0	1
LADY MINTO HOSPITAL - COCHRANE	AB+	0	0	0	1

Hospital Name	Type	Historic s	Historic S	New s	New S
LADY MINTO HOSPITAL - COCHRANE	B-	0	0	0	1
LADY MINTO HOSPITAL - COCHRANE	B+	0	0	0	1
LADY MINTO HOSPITAL - COCHRANE	O-	1	4	1	2
LADY MINTO HOSPITAL - COCHRANE	O+	0	4	1	3
MANITOULIN HEALTH CENTRE- L.CURRENT	A-	0	0	0	0
MANITOULIN HEALTH CENTRE- L.CURRENT	A+	1	5	4	5
MANITOULIN HEALTH CENTRE- L.CURRENT	AB-	0	0	0	1
MANITOULIN HEALTH CENTRE- L.CURRENT	AB+	0	0	0	1
MANITOULIN HEALTH CENTRE- L.CURRENT	B-	0	0	0	1
MANITOULIN HEALTH CENTRE- L.CURRENT	B+	0	0	0	2
MANITOULIN HEALTH CENTRE- L.CURRENT	O-	4	6	1	2
MANITOULIN HEALTH CENTRE- L.CURRENT	O+	2	5	4	6
BINGHAM MEMORIAL HOSPITAL - MATHESON	A-	0	0	0	1
BINGHAM MEMORIAL HOSPITAL - MATHESON	A+	0	0	0	1
BINGHAM MEMORIAL HOSPITAL - MATHESON	AB-	0	0	0	1
BINGHAM MEMORIAL HOSPITAL - MATHESON	AB+	0	0	0	1
BINGHAM MEMORIAL HOSPITAL - MATHESON	B-	0	0	0	1
BINGHAM MEMORIAL HOSPITAL - MATHESON	B+	0	0	0	1
BINGHAM MEMORIAL HOSPITAL - MATHESON	O-	0	2	0	1
BINGHAM MEMORIAL HOSPITAL - MATHESON	O+	0	0	0	1
LADY DUNN HEALTH CENTRE	A-	0	0	0	1
LADY DUNN HEALTH CENTRE	A+	0	0	0	0
LADY DUNN HEALTH CENTRE	AB-	0	0	0	1
LADY DUNN HEALTH CENTRE	AB+	0	0	0	1
LADY DUNN HEALTH CENTRE	B-	0	0	0	1
LADY DUNN HEALTH CENTRE	B+	0	0	0	1
LADY DUNN HEALTH CENTRE	O-	2	5	0	1
LADY DUNN HEALTH CENTRE	O+	1	4	1	3
NORTH BAY REGIONAL HEALTH CENTRE	A-	6	10	4	5
NORTH BAY REGIONAL HEALTH CENTRE	A+	20	25	34	36
NORTH BAY REGIONAL HEALTH CENTRE	AB-	0	0	0	1
NORTH BAY REGIONAL HEALTH CENTRE	AB+	0	0	2	3
NORTH BAY REGIONAL HEALTH CENTRE	B-	0	2	1	2
NORTH BAY REGIONAL HEALTH CENTRE	B+	2	4	6	7
NORTH BAY REGIONAL HEALTH CENTRE	O-	11	15	5	6
NORTH BAY REGIONAL HEALTH CENTRE	O+	30	35	34	36
NOTRE DAME HOSPITAL HEARST	A-	0	0	0	1
NOTRE DAME HOSPITAL HEARST	A+	0	0	0	0
NOTRE DAME HOSPITAL HEARST	AB-	0	0	0	1

Hospital Name	Type	Historic s	Historic S	New s	New S
NOTRE DAME HOSPITAL HEARST	AB+	0	0	0	1
NOTRE DAME HOSPITAL HEARST	B-	0	0	0	1
NOTRE DAME HOSPITAL HEARST	B+	0	0	0	1
NOTRE DAME HOSPITAL HEARST	O-	1	4	0	1
NOTRE DAME HOSPITAL HEARST	O+	1	4	1	3
SAULT AREA HOSPITALS	A-	5	10	7	9
SAULT AREA HOSPITALS	A+	40	51	57	59
SAULT AREA HOSPITALS	AB-	0	1	0	1
SAULT AREA HOSPITALS	AB+	0	0	3	4
SAULT AREA HOSPITALS	B-	1	4	1	3
SAULT AREA HOSPITALS	B+	3	8	10	12
SAULT AREA HOSPITALS	O-	17	22	9	11
SAULT AREA HOSPITALS	O+	46	56	54	57
SENSENBRENNER HOSPITAL KAPUSKASING	A-	0	0	0	1
SENSENBRENNER HOSPITAL KAPUSKASING	A+	0	0	0	0
SENSENBRENNER HOSPITAL KAPUSKASING	AB-	0	0	0	1
SENSENBRENNER HOSPITAL KAPUSKASING	AB+	0	0	0	1
SENSENBRENNER HOSPITAL KAPUSKASING	B-	0	0	0	1
SENSENBRENNER HOSPITAL KAPUSKASING	B+	0	0	0	1
SENSENBRENNER HOSPITAL KAPUSKASING	O-	2	5	1	2
SENSENBRENNER HOSPITAL KAPUSKASING	O+	2	6	2	4
SMOOTH ROCK FALLS HOSPITAL	A-	0	0	0	0
SMOOTH ROCK FALLS HOSPITAL	A+	0	0	0	0
SMOOTH ROCK FALLS HOSPITAL	AB-	0	0	0	1
SMOOTH ROCK FALLS HOSPITAL	AB+	0	0	0	1
SMOOTH ROCK FALLS HOSPITAL	B-	0	0	0	1
SMOOTH ROCK FALLS HOSPITAL	B+	0	0	0	1
SMOOTH ROCK FALLS HOSPITAL	O-	0	2	0	1
SMOOTH ROCK FALLS HOSPITAL	O+	1	2	1	2
ST JOSEPH'S GENERAL - ELLIOT LAKE	A-	0	0	0	1
ST JOSEPH'S GENERAL - ELLIOT LAKE	A+	1	2	6	7
ST JOSEPH'S GENERAL - ELLIOT LAKE	AB-	0	0	0	1
ST JOSEPH'S GENERAL - ELLIOT LAKE	AB+	0	0	0	1
ST JOSEPH'S GENERAL - ELLIOT LAKE	B-	0	0	0	1
ST JOSEPH'S GENERAL - ELLIOT LAKE	B+	0	0	1	2
ST JOSEPH'S GENERAL - ELLIOT LAKE	O-	2	5	0	2
ST JOSEPH'S GENERAL - ELLIOT LAKE	O+	4	8	4	6
HEALTH SCIENCES NORTH	A-	6	10	9	10
HEALTH SCIENCES NORTH	A+	39	50	58	61

Hospital Name	Type	Historics	HistoricS	News	NewS
HEALTH SCIENCES NORTH	AB-	1	2	0	1
HEALTH SCIENCES NORTH	AB+	2	2	4	5
HEALTH SCIENCES NORTH	B-	3	6	2	3
HEALTH SCIENCES NORTH	B+	5	10	12	14
HEALTH SCIENCES NORTH	O-	24	30	13	15
HEALTH SCIENCES NORTH	O+	43	55	60	63
TEMISKAMING HOSPITAL NEW LISKEARD	A-	1	4	1	2
TEMISKAMING HOSPITAL NEW LISKEARD	A+	5	8	9	11
TEMISKAMING HOSPITAL NEW LISKEARD	AB-	0	0	0	1
TEMISKAMING HOSPITAL NEW LISKEARD	AB+	0	0	0	1
TEMISKAMING HOSPITAL NEW LISKEARD	B-	0	0	0	1
TEMISKAMING HOSPITAL NEW LISKEARD	B+	0	0	2	3
TEMISKAMING HOSPITAL NEW LISKEARD	O-	3	6	2	3
TEMISKAMING HOSPITAL NEW LISKEARD	O+	6	10	8	10
TIMMINS & DISTRICT HOSPITAL	A-	1	4	2	3
TIMMINS & DISTRICT HOSPITAL	A+	7	12	12	14
TIMMINS & DISTRICT HOSPITAL	AB-	0	0	0	1
TIMMINS & DISTRICT HOSPITAL	AB+	0	0	1	2
TIMMINS & DISTRICT HOSPITAL	B-	0	0	0	1
TIMMINS & DISTRICT HOSPITAL	B+	0	0	3	4
TIMMINS & DISTRICT HOSPITAL	O-	5	8	3	4
TIMMINS & DISTRICT HOSPITAL	O+	11	17	13	15
WEENEEBAYKO HOSPITAL MOOSE FACTORY	A-	0	0	0	1
WEENEEBAYKO HOSPITAL MOOSE FACTORY	A+	0	0	0	0
WEENEEBAYKO HOSPITAL MOOSE FACTORY	AB-	0	0	0	1
WEENEEBAYKO HOSPITAL MOOSE FACTORY	AB+	0	0	0	1
WEENEEBAYKO HOSPITAL MOOSE FACTORY	B-	0	0	0	1
WEENEEBAYKO HOSPITAL MOOSE FACTORY	B+	0	0	0	2
WEENEEBAYKO HOSPITAL MOOSE FACTORY	O-	3	8	1	2
WEENEEBAYKO HOSPITAL MOOSE FACTORY	O+	5	12	5	8
WEST NIPISSING HOSPITAL STURGEON FALLS	A-	1	2	1	2
WEST NIPISSING HOSPITAL STURGEON FALLS	A+	1	2	3	4
WEST NIPISSING HOSPITAL STURGEON FALLS	AB-	0	0	0	1
WEST NIPISSING HOSPITAL STURGEON FALLS	AB+	0	0	0	1
WEST NIPISSING HOSPITAL STURGEON FALLS	B-	0	0	0	1
WEST NIPISSING HOSPITAL STURGEON FALLS	B+	0	0	1	2
WEST NIPISSING HOSPITAL STURGEON FALLS	O-	1	4	1	2
WEST NIPISSING HOSPITAL STURGEON FALLS	O+	3	6	4	5
QUINTE HEALTHCARE - TRENTON MEMORIAL	A-	1	2	0	2

Hospital Name	Type	Historics	HistoricS	News	NewS
QUINTE HEALTHCARE - TRENTON MEMORIAL	A+	2	6	5	6
QUINTE HEALTHCARE - TRENTON MEMORIAL	AB-	0	0	0	1
QUINTE HEALTHCARE - TRENTON MEMORIAL	AB+	0	0	0	1
QUINTE HEALTHCARE - TRENTON MEMORIAL	B-	0	0	0	1
QUINTE HEALTHCARE - TRENTON MEMORIAL	B+	0	0	1	2
QUINTE HEALTHCARE - TRENTON MEMORIAL	O-	2	4	2	3
QUINTE HEALTHCARE - TRENTON MEMORIAL	O+	2	6	5	7
LENNOX & ADDINGTON COUNTY GENERAL HOSP	A-	1	2	1	2
LENNOX & ADDINGTON COUNTY GENERAL HOSP	A+	2	5	4	6
LENNOX & ADDINGTON COUNTY GENERAL HOSP	AB-	0	0	0	1
LENNOX & ADDINGTON COUNTY GENERAL HOSP	AB+	0	0	0	1
LENNOX & ADDINGTON COUNTY GENERAL HOSP	B-	0	0	0	1
LENNOX & ADDINGTON COUNTY GENERAL HOSP	B+	0	0	1	2
LENNOX & ADDINGTON COUNTY GENERAL HOSP	O-	1	3	1	2
LENNOX & ADDINGTON COUNTY GENERAL HOSP	O+	3	6	5	6
QUINTE HEALTHCARE - BELLEVILLE GENERAL	A-	5	8	5	7
QUINTE HEALTHCARE - BELLEVILLE GENERAL	A+	28	35	35	37
QUINTE HEALTHCARE - BELLEVILLE GENERAL	AB-	0	0	0	1
QUINTE HEALTHCARE - BELLEVILLE GENERAL	AB+	0	0	2	3
QUINTE HEALTHCARE - BELLEVILLE GENERAL	B-	0	0	1	2
QUINTE HEALTHCARE - BELLEVILLE GENERAL	B+	3	6	7	8
QUINTE HEALTHCARE - BELLEVILLE GENERAL	O-	8	12	5	7
QUINTE HEALTHCARE - BELLEVILLE GENERAL	O+	33	40	40	43
ALEXANDRIA- GLENGARRY MEMORIAL	A-	1	2	0	1
ALEXANDRIA- GLENGARRY MEMORIAL	A+	1	2	3	4
ALEXANDRIA- GLENGARRY MEMORIAL	AB-	0	0	0	1
ALEXANDRIA- GLENGARRY MEMORIAL	AB+	0	0	0	1
ALEXANDRIA- GLENGARRY MEMORIAL	B-	0	0	0	1
ALEXANDRIA- GLENGARRY MEMORIAL	B+	0	0	0	1
ALEXANDRIA- GLENGARRY MEMORIAL	O-	2	4	0	1
ALEXANDRIA- GLENGARRY MEMORIAL	O+	1	2	2	3
ALMONTE GENERAL	A-	1	4	0	1
ALMONTE GENERAL	A+	0	0	0	0
ALMONTE GENERAL	AB-	0	0	0	1
ALMONTE GENERAL	AB+	0	0	0	1
ALMONTE GENERAL	B-	0	0	0	1
ALMONTE GENERAL	B+	0	0	0	1
ALMONTE GENERAL	O-	1	4	1	2
ALMONTE GENERAL	O+	3	6	4	6

Hospital Name	Type	Historics	HistoricS	News	NewS
ARNPRIOR & DISTRICT	A-	2	2	0	1
ARNPRIOR & DISTRICT	A+	3	6	9	11
ARNPRIOR & DISTRICT	AB-	0	0	0	1
ARNPRIOR & DISTRICT	AB+	0	0	0	1
ARNPRIOR & DISTRICT	B-	0	0	0	1
ARNPRIOR & DISTRICT	B+	0	0	1	2
ARNPRIOR & DISTRICT	O-	2	4	2	3
ARNPRIOR & DISTRICT	O+	3	6	4	6
QIKIQTANI GENERAL HOSPITAL	A-	1	2	1	2
QIKIQTANI GENERAL HOSPITAL	A+	2	5	5	7
QIKIQTANI GENERAL HOSPITAL	AB-	0	0	0	1
QIKIQTANI GENERAL HOSPITAL	AB+	0	0	0	1
QIKIQTANI GENERAL HOSPITAL	B-	0	0	0	1
QIKIQTANI GENERAL HOSPITAL	B+	0	0	1	2
QIKIQTANI GENERAL HOSPITAL	O-	1	3	0	2
QIKIQTANI GENERAL HOSPITAL	O+	4	8	6	8
BARRY'S BAY- ST. FRANCIS	A-	0	0	0	1
BARRY'S BAY- ST. FRANCIS	A+	0	0	4	6
BARRY'S BAY- ST. FRANCIS	AB-	0	0	0	1
BARRY'S BAY- ST. FRANCIS	AB+	0	0	0	1
BARRY'S BAY- ST. FRANCIS	B-	0	0	0	1
BARRY'S BAY- ST. FRANCIS	B+	0	0	0	2
BARRY'S BAY- ST. FRANCIS	O-	4	7	0	2
BARRY'S BAY- ST. FRANCIS	O+	4	7	4	6
BROCKVILLE GENERAL	A-	8	12	5	6
BROCKVILLE GENERAL	A+	10	16	15	17
BROCKVILLE GENERAL	AB-	0	0	0	1
BROCKVILLE GENERAL	AB+	0	0	1	2
BROCKVILLE GENERAL	B-	1	4	0	1
BROCKVILLE GENERAL	B+	0	0	4	6
BROCKVILLE GENERAL	O-	9	12	6	7
BROCKVILLE GENERAL	O+	11	16	17	19
CAN FORCES HEALTH SERVICES CENTRE OTTAWA	A-	0	0	0	0
CAN FORCES HEALTH SERVICES CENTRE OTTAWA	A+	0	0	0	0
CAN FORCES HEALTH SERVICES CENTRE OTTAWA	AB-	0	0	0	0
CAN FORCES HEALTH SERVICES CENTRE OTTAWA	AB+	0	0	0	0
CAN FORCES HEALTH SERVICES CENTRE OTTAWA	B-	0	0	0	0
CAN FORCES HEALTH SERVICES CENTRE OTTAWA	B+	0	0	0	0
CAN FORCES HEALTH SERVICES CENTRE OTTAWA	O-	0	0	0	0

Hospital Name	Type	Historics	HistoricS	News	NewS
CAN FORCES HEALTH SERVICES CENTRE OTTAWA	O+	0	0	0	0
CARLETON PLACE AND DISTRICT	A-	0	0	0	0
CARLETON PLACE AND DISTRICT	A+	1	4	3	5
CARLETON PLACE AND DISTRICT	AB-	0	0	0	1
CARLETON PLACE AND DISTRICT	AB+	0	0	0	1
CARLETON PLACE AND DISTRICT	B-	0	0	0	1
CARLETON PLACE AND DISTRICT	B+	0	0	0	1
CARLETON PLACE AND DISTRICT	O-	2	4	1	2
CARLETON PLACE AND DISTRICT	O+	3	6	4	6
CHILDREN'S HOSPITAL OF EASTERN ONTARIO	A-	1	2	2	3
CHILDREN'S HOSPITAL OF EASTERN ONTARIO	A+	2	5	9	11
CHILDREN'S HOSPITAL OF EASTERN ONTARIO	AB-	0	0	0	1
CHILDREN'S HOSPITAL OF EASTERN ONTARIO	AB+	0	0	0	1
CHILDREN'S HOSPITAL OF EASTERN ONTARIO	B-	0	0	0	1
CHILDREN'S HOSPITAL OF EASTERN ONTARIO	B+	1	2	2	3
CHILDREN'S HOSPITAL OF EASTERN ONTARIO	O-	11	15	2	3
CHILDREN'S HOSPITAL OF EASTERN ONTARIO	O+	7	10	10	11
CORNWALL COMMUNITY, MCCONNELL SITE	A-	3	6	5	6
CORNWALL COMMUNITY, MCCONNELL SITE	A+	22	30	29	31
CORNWALL COMMUNITY, MCCONNELL SITE	AB-	0	0	0	1
CORNWALL COMMUNITY, MCCONNELL SITE	AB+	0	0	1	3
CORNWALL COMMUNITY, MCCONNELL SITE	B-	1	3	1	2
CORNWALL COMMUNITY, MCCONNELL SITE	B+	0	0	5	7
CORNWALL COMMUNITY, MCCONNELL SITE	O-	6	10	5	6
CORNWALL COMMUNITY, MCCONNELL SITE	O+	21	30	25	27
DEEP RIVER AND DISTRICT	A-	0	0	0	0
DEEP RIVER AND DISTRICT	A+	0	0	0	0
DEEP RIVER AND DISTRICT	AB-	0	0	0	1
DEEP RIVER AND DISTRICT	AB+	0	0	0	1
DEEP RIVER AND DISTRICT	B-	0	0	0	1
DEEP RIVER AND DISTRICT	B+	0	0	0	1
DEEP RIVER AND DISTRICT	O-	1	4	0	1
DEEP RIVER AND DISTRICT	O+	1	4	2	4
HAWKESBURY GENERAL	A-	2	4	1	2
HAWKESBURY GENERAL	A+	4	6	11	12
HAWKESBURY GENERAL	AB-	0	0	0	1
HAWKESBURY GENERAL	AB+	0	0	0	1
HAWKESBURY GENERAL	B-	0	0	0	1
HAWKESBURY GENERAL	B+	0	0	2	3

Hospital Name	Type	Historics	HistoricS	News	NewS
HAWKESBURY GENERAL	O-	5	8	2	3
HAWKESBURY GENERAL	O+	5	8	6	8
KEMPTVILLE DISTRICT	A-	0	0	0	0
KEMPTVILLE DISTRICT	A+	1	4	3	5
KEMPTVILLE DISTRICT	AB-	0	0	0	1
KEMPTVILLE DISTRICT	AB+	0	0	0	1
KEMPTVILLE DISTRICT	B-	0	0	0	1
KEMPTVILLE DISTRICT	B+	0	0	0	1
KEMPTVILLE DISTRICT	O-	2	4	1	2
KEMPTVILLE DISTRICT	O+	3	6	5	7
KINGSTON GENERAL	A-	15	20	16	17
KINGSTON GENERAL	A+	83	100	105	109
KINGSTON GENERAL	AB-	0	0	1	2
KINGSTON GENERAL	AB+	0	0	6	7
KINGSTON GENERAL	B-	6	10	3	4
KINGSTON GENERAL	B+	9	15	19	21
KINGSTON GENERAL	O-	19	25	15	17
KINGSTON GENERAL	O+	82	100	95	99
QUEENSWAY CARLETON- NEPEAN	A-	5	8	5	7
QUEENSWAY CARLETON- NEPEAN	A+	13	20	24	26
QUEENSWAY CARLETON- NEPEAN	AB-	2	2	0	1
QUEENSWAY CARLETON- NEPEAN	AB+	0	0	1	2
QUEENSWAY CARLETON- NEPEAN	B-	2	2	1	2
QUEENSWAY CARLETON- NEPEAN	B+	2	2	5	6
QUEENSWAY CARLETON- NEPEAN	O-	5	8	6	7
QUEENSWAY CARLETON- NEPEAN	O+	12	20	18	20
OTTAWA MONTFORT	A-	5	8	6	8
OTTAWA MONTFORT	A+	19	25	30	32
OTTAWA MONTFORT	AB-	2	2	0	1
OTTAWA MONTFORT	AB+	0	0	1	3
OTTAWA MONTFORT	B-	2	2	1	2
OTTAWA MONTFORT	B+	4	4	6	7
OTTAWA MONTFORT	O-	3	6	3	4
OTTAWA MONTFORT	O+	19	25	25	27
OTTAWA HOSPITAL CIVIC CAMPUS	A-	12	20	15	16
OTTAWA HOSPITAL CIVIC CAMPUS	A+	62	80	90	94
OTTAWA HOSPITAL CIVIC CAMPUS	AB-	1	2	1	2
OTTAWA HOSPITAL CIVIC CAMPUS	AB+	2	4	6	7
OTTAWA HOSPITAL CIVIC CAMPUS	B-	2	4	3	4

Hospital Name	Type	Historic s	Historic S	New s	New S
OTTAWA HOSPITAL CIVIC CAMPUS	B+	11	20	19	21
OTTAWA HOSPITAL CIVIC CAMPUS	O-	24	30	23	24
OTTAWA HOSPITAL CIVIC CAMPUS	O+	60	80	77	81
OTTAWA HOSPITAL- GENERAL CAMPUS	A-	12	20	14	16
OTTAWA HOSPITAL- GENERAL CAMPUS	A+	70	90	105	109
OTTAWA HOSPITAL- GENERAL CAMPUS	AB-	2	2	1	2
OTTAWA HOSPITAL- GENERAL CAMPUS	AB+	2	4	6	7
OTTAWA HOSPITAL- GENERAL CAMPUS	B-	2	6	3	4
OTTAWA HOSPITAL- GENERAL CAMPUS	B+	12	20	20	21
OTTAWA HOSPITAL- GENERAL CAMPUS	O-	23	30	21	22
OTTAWA HOSPITAL- GENERAL CAMPUS	O+	66	90	86	90
OTTAWA HOSPITAL RIVERSIDE CAMPUS	A-	2	4	1	3
OTTAWA HOSPITAL RIVERSIDE CAMPUS	A+	2	4	4	5
OTTAWA HOSPITAL RIVERSIDE CAMPUS	AB-	0	0	0	1
OTTAWA HOSPITAL RIVERSIDE CAMPUS	AB+	0	0	0	1
OTTAWA HOSPITAL RIVERSIDE CAMPUS	B-	0	0	0	1
OTTAWA HOSPITAL RIVERSIDE CAMPUS	B+	0	0	1	2
OTTAWA HOSPITAL RIVERSIDE CAMPUS	O-	2	4	2	3
OTTAWA HOSPITAL RIVERSIDE CAMPUS	O+	2	4	5	6
PEMBROKE REGIONAL HOSPITAL	A-	1	4	3	4
PEMBROKE REGIONAL HOSPITAL	A+	9	15	14	16
PEMBROKE REGIONAL HOSPITAL	AB-	0	0	0	1
PEMBROKE REGIONAL HOSPITAL	AB+	0	0	1	2
PEMBROKE REGIONAL HOSPITAL	B-	0	0	0	1
PEMBROKE REGIONAL HOSPITAL	B+	0	0	3	5
PEMBROKE REGIONAL HOSPITAL	O-	8	12	4	5
PEMBROKE REGIONAL HOSPITAL	O+	12	18	15	18
SMITH FALLS SITE P&SFDH	A-	2	2	0	1
SMITH FALLS SITE P&SFDH	A+	2	2	3	5
SMITH FALLS SITE P&SFDH	AB-	0	0	0	1
SMITH FALLS SITE P&SFDH	AB+	0	0	0	1
SMITH FALLS SITE P&SFDH	B-	0	0	0	1
SMITH FALLS SITE P&SFDH	B+	0	0	0	2
SMITH FALLS SITE P&SFDH	O-	2	4	1	2
SMITH FALLS SITE P&SFDH	O+	2	6	4	5
PERTH SITE P&SFDH	A-	1	4	0	1
PERTH SITE P&SFDH	A+	2	2	3	5
PERTH SITE P&SFDH	AB-	0	0	0	1
PERTH SITE P&SFDH	AB+	0	0	0	1

Hospital Name	Type	Historic s	Historic S	New s	New S
PERTH SITE P&SFDH	B-	0	0	0	1
PERTH SITE P&SFDH	B+	0	0	1	2
PERTH SITE P&SFDH	O-	1	4	2	3
PERTH SITE P&SFDH	O+	5	10	9	11
RENFREW VICTORIA	A-	2	4	1	2
RENFREW VICTORIA	A+	2	2	3	5
RENFREW VICTORIA	AB-	0	0	0	1
RENFREW VICTORIA	AB+	0	0	0	1
RENFREW VICTORIA	B-	0	0	0	1
RENFREW VICTORIA	B+	0	0	1	2
RENFREW VICTORIA	O-	3	6	2	3
RENFREW VICTORIA	O+	3	8	5	7
WINCHESTER AND DISTRICT	A-	0	0	0	0
WINCHESTER AND DISTRICT	A+	2	6	5	6
WINCHESTER AND DISTRICT	AB-	0	0	0	1
WINCHESTER AND DISTRICT	AB+	0	0	0	1
WINCHESTER AND DISTRICT	B-	0	0	0	1
WINCHESTER AND DISTRICT	B+	0	0	0	2
WINCHESTER AND DISTRICT	O-	3	6	1	2
WINCHESTER AND DISTRICT	O+	3	6	6	7

Table C2- List of historic versus new (s, S) for all hospitals and types in Ottawa

Hospital Name	Type	Historic s	Historic S	New s	New S
BURNABY HOSPITAL	A-	4	6	5	6
BURNABY HOSPITAL	A+	13	20	23	26
BURNABY HOSPITAL	AB-	1	2	0	1
BURNABY HOSPITAL	AB+	3	4	2	3
BURNABY HOSPITAL	B-	1	2	1	2
BURNABY HOSPITAL	B+	4	8	7	9
BURNABY HOSPITAL	O-	6	8	7	8
BURNABY HOSPITAL	O+	23	32	32	35
BURNS LAKE DISTR. INTG. & HLTH SERVICES	A-	1	2	0	1
BURNS LAKE DISTR. INTG. & HLTH SERVICES	A+	1	2	3	5
BURNS LAKE DISTR. INTG. & HLTH SERVICES	AB-	0	0	0	1
BURNS LAKE DISTR. INTG. & HLTH SERVICES	AB+	0	1	0	1
BURNS LAKE DISTR. INTG. & HLTH SERVICES	B-	0	1	0	1
BURNS LAKE DISTR. INTG. & HLTH SERVICES	B+	0	0	0	2

Hospital Name	Type	Historic s	Historic S	New s	New S
BURNS LAKE DISTR. INTG. & HLTH SERVICES	O-	1	2	0	1
BURNS LAKE DISTR. INTG. & HLTH SERVICES	O+	1	2	1	3
CAMPBELL RIVER & DISTRICT GENERAL HOSP.	A-	2	3	1	2
CAMPBELL RIVER & DISTRICT GENERAL HOSP.	A+	3	4	3	6
CAMPBELL RIVER & DISTRICT GENERAL HOSP.	AB-	0	0	0	1
CAMPBELL RIVER & DISTRICT GENERAL HOSP.	AB+	1	2	0	1
CAMPBELL RIVER & DISTRICT GENERAL HOSP.	B-	1	2	0	1
CAMPBELL RIVER & DISTRICT GENERAL HOSP.	B+	1	2	1	2
CAMPBELL RIVER & DISTRICT GENERAL HOSP.	O-	2	3	1	2
CAMPBELL RIVER & DISTRICT GENERAL HOSP.	O+	3	4	2	5
CASTLEGAR & DIST. COMM. HLTH CARE CENTRE	A-	1	2	1	2
CASTLEGAR & DIST. COMM. HLTH CARE CENTRE	A+	1	2	2	4
CASTLEGAR & DIST. COMM. HLTH CARE CENTRE	AB-	0	0	0	1
CASTLEGAR & DIST. COMM. HLTH CARE CENTRE	AB+	0	0	0	1
CASTLEGAR & DIST. COMM. HLTH CARE CENTRE	B-	1	2	0	1
CASTLEGAR & DIST. COMM. HLTH CARE CENTRE	B+	1	2	1	2
CASTLEGAR & DIST. COMM. HLTH CARE CENTRE	O-	1	2	0	1
CASTLEGAR & DIST. COMM. HLTH CARE CENTRE	O+	0	0	0	0
CHILLIWACK GENERAL HOSPITAL	A-	9	12	8	10
CHILLIWACK GENERAL HOSPITAL	A+	31	40	44	47
CHILLIWACK GENERAL HOSPITAL	AB-	0	0	0	1
CHILLIWACK GENERAL HOSPITAL	AB+	1	2	3	4
CHILLIWACK GENERAL HOSPITAL	B-	1	2	2	3
CHILLIWACK GENERAL HOSPITAL	B+	8	10	11	12
CHILLIWACK GENERAL HOSPITAL	O-	9	12	8	10
CHILLIWACK GENERAL HOSPITAL	O+	29	40	35	38
COMOX ST. JOSEPH'S GENERAL HOSPITAL	A-	8	10	5	6
COMOX ST. JOSEPH'S GENERAL HOSPITAL	A+	21	25	34	36
COMOX ST. JOSEPH'S GENERAL HOSPITAL	AB-	0	0	0	1
COMOX ST. JOSEPH'S GENERAL HOSPITAL	AB+	1	2	2	3
COMOX ST. JOSEPH'S GENERAL HOSPITAL	B-	5	6	1	2
COMOX ST. JOSEPH'S GENERAL HOSPITAL	B+	1	3	8	9
COMOX ST. JOSEPH'S GENERAL HOSPITAL	O-	14	17	7	8
COMOX ST. JOSEPH'S GENERAL HOSPITAL	O+	21	26	29	31
DELTA HOSPITAL	A-	1	2	1	2
DELTA HOSPITAL	A+	3	4	4	6
DELTA HOSPITAL	AB-	1	2	0	1
DELTA HOSPITAL	AB+	1	2	0	1
DELTA HOSPITAL	B-	1	2	0	1

Hospital Name	Type	Historic s	Historic S	New s	New S
DELTA HOSPITAL	B+	2	3	1	3
DELTA HOSPITAL	O-	1	2	1	2
DELTA HOSPITAL	O+	3	4	3	5
DUNCAN COWICHAN DISTRICT HOSPITAL	A-	2	2	1	3
DUNCAN COWICHAN DISTRICT HOSPITAL	A+	3	4	4	6
DUNCAN COWICHAN DISTRICT HOSPITAL	AB-	0	0	0	1
DUNCAN COWICHAN DISTRICT HOSPITAL	AB+	1	2	1	2
DUNCAN COWICHAN DISTRICT HOSPITAL	B-	1	2	0	1
DUNCAN COWICHAN DISTRICT HOSPITAL	B+	1	2	4	5
DUNCAN COWICHAN DISTRICT HOSPITAL	O-	3	4	1	3
DUNCAN COWICHAN DISTRICT HOSPITAL	O+	20	30	22	25
STUART LAKE HOSPITAL	A-	0	0	0	1
STUART LAKE HOSPITAL	A+	0	0	0	2
STUART LAKE HOSPITAL	AB-	0	0	0	1
STUART LAKE HOSPITAL	AB+	0	0	0	1
STUART LAKE HOSPITAL	B-	0	0	0	1
STUART LAKE HOSPITAL	B+	0	0	0	1
STUART LAKE HOSPITAL	O-	1	2	0	1
STUART LAKE HOSPITAL	O+	1	2	0	2
FORT ST. JOHN HOSPITAL/PEACE VILLA LAB	A-	0	0	0	1
FORT ST. JOHN HOSPITAL/PEACE VILLA LAB	A+	0	0	0	0
FORT ST. JOHN HOSPITAL/PEACE VILLA LAB	AB-	0	0	0	1
FORT ST. JOHN HOSPITAL/PEACE VILLA LAB	AB+	0	0	0	1
FORT ST. JOHN HOSPITAL/PEACE VILLA LAB	B-	0	0	0	1
FORT ST. JOHN HOSPITAL/PEACE VILLA LAB	B+	0	0	0	1
FORT ST. JOHN HOSPITAL/PEACE VILLA LAB	O-	1	2	0	1
FORT ST. JOHN HOSPITAL/PEACE VILLA LAB	O+	1	2	0	2
GRAND FORKS BOUNDARY HOSPITAL	A-	1	2	0	1
GRAND FORKS BOUNDARY HOSPITAL	A+	2	3	3	5
GRAND FORKS BOUNDARY HOSPITAL	AB-	0	0	0	1
GRAND FORKS BOUNDARY HOSPITAL	AB+	0	0	0	1
GRAND FORKS BOUNDARY HOSPITAL	B-	0	0	0	1
GRAND FORKS BOUNDARY HOSPITAL	B+	1	2	0	2
GRAND FORKS BOUNDARY HOSPITAL	O-	1	2	0	1
GRAND FORKS BOUNDARY HOSPITAL	O+	2	3	3	5
HAZELTON WRINCH MEMORIAL HOSPITAL	A-	1	2	0	1
HAZELTON WRINCH MEMORIAL HOSPITAL	A+	1	2	4	6
HAZELTON WRINCH MEMORIAL HOSPITAL	AB-	0	0	0	1
HAZELTON WRINCH MEMORIAL HOSPITAL	AB+	0	0	0	1

Hospital Name	Type	Historic s	Historic S	New s	New S
HAZELTON WRINCH MEMORIAL HOSPITAL	B-	0	0	0	1
HAZELTON WRINCH MEMORIAL HOSPITAL	B+	0	0	1	2
HAZELTON WRINCH MEMORIAL HOSPITAL	O-	1	2	0	1
HAZELTON WRINCH MEMORIAL HOSPITAL	O+	2	3	1	3
FRASER CANYON HOSPITAL	A-	1	2	0	2
FRASER CANYON HOSPITAL	A+	2	3	2	4
FRASER CANYON HOSPITAL	AB-	1	2	0	1
FRASER CANYON HOSPITAL	AB+	0	0	0	1
FRASER CANYON HOSPITAL	B-	1	2	0	1
FRASER CANYON HOSPITAL	B+	0	0	1	2
FRASER CANYON HOSPITAL	O-	1	2	0	1
FRASER CANYON HOSPITAL	O+	2	3	3	5
ROYAL INLAND HOSPITAL	A-	9	12	7	9
ROYAL INLAND HOSPITAL	A+	32	40	44	47
ROYAL INLAND HOSPITAL	AB-	0	0	0	1
ROYAL INLAND HOSPITAL	AB+	1	2	3	4
ROYAL INLAND HOSPITAL	B-	1	2	2	3
ROYAL INLAND HOSPITAL	B+	8	10	11	12
ROYAL INLAND HOSPITAL	O-	19	23	10	11
ROYAL INLAND HOSPITAL	O+	36	45	49	52
KELOWNA GENERAL HOSPITAL	A-	22	25	14	15
KELOWNA GENERAL HOSPITAL	A+	51	60	73	76
KELOWNA GENERAL HOSPITAL	AB-	5	6	1	2
KELOWNA GENERAL HOSPITAL	AB+	9	10	6	7
KELOWNA GENERAL HOSPITAL	B-	5	6	3	4
KELOWNA GENERAL HOSPITAL	B+	12	15	18	19
KELOWNA GENERAL HOSPITAL	O-	26	30	16	17
KELOWNA GENERAL HOSPITAL	O+	59	70	77	81
KITIMAT GENERAL HOSPITAL	A-	1	2	0	2
KITIMAT GENERAL HOSPITAL	A+	2	3	1	4
KITIMAT GENERAL HOSPITAL	AB-	0	0	0	1
KITIMAT GENERAL HOSPITAL	AB+	1	2	0	1
KITIMAT GENERAL HOSPITAL	B-	1	2	0	1
KITIMAT GENERAL HOSPITAL	B+	0	0	0	2
KITIMAT GENERAL HOSPITAL	O-	2	3	0	1
KITIMAT GENERAL HOSPITAL	O+	2	3	3	6
LANGLEY MEMORIAL HOSPITAL	A-	6	8	7	8
LANGLEY MEMORIAL HOSPITAL	A+	21	30	31	34
LANGLEY MEMORIAL HOSPITAL	AB-	3	4	0	1

Hospital Name	Type	Historics	HistoricS	News	New S
LANGLEY MEMORIAL HOSPITAL	AB+	2	4	3	4
LANGLEY MEMORIAL HOSPITAL	B-	3	4	1	2
LANGLEY MEMORIAL HOSPITAL	B+	5	8	10	11
LANGLEY MEMORIAL HOSPITAL	O-	7	10	9	10
LANGLEY MEMORIAL HOSPITAL	O+	21	30	32	35
LILLOOET DISTRICT HOSPITAL	A-	1	2	0	2
LILLOOET DISTRICT HOSPITAL	A+	1	2	1	3
LILLOOET DISTRICT HOSPITAL	AB-	0	0	0	1
LILLOOET DISTRICT HOSPITAL	AB+	0	0	0	1
LILLOOET DISTRICT HOSPITAL	B-	0	0	0	1
LILLOOET DISTRICT HOSPITAL	B+	0	0	1	2
LILLOOET DISTRICT HOSPITAL	O-	1	2	0	1
LILLOOET DISTRICT HOSPITAL	O+	1	2	1	3
MACKENZIE & DISTRICT HOSPITAL	A-	0	0	0	1
MACKENZIE & DISTRICT HOSPITAL	A+	0	0	0	2
MACKENZIE & DISTRICT HOSPITAL	AB-	0	0	0	1
MACKENZIE & DISTRICT HOSPITAL	AB+	0	0	0	1
MACKENZIE & DISTRICT HOSPITAL	B-	0	0	0	1
MACKENZIE & DISTRICT HOSPITAL	B+	0	0	0	1
MACKENZIE & DISTRICT HOSPITAL	O-	1	2	0	1
MACKENZIE & DISTRICT HOSPITAL	O+	1	2	0	2
NORTHERN HAIDA GWAII HOSPITAL	A-	1	2	17	18
NORTHERN HAIDA GWAII HOSPITAL	A+	1	2	2	4
NORTHERN HAIDA GWAII HOSPITAL	AB-	0	0	0	1
NORTHERN HAIDA GWAII HOSPITAL	AB+	0	0	0	1
NORTHERN HAIDA GWAII HOSPITAL	B-	0	0	0	1
NORTHERN HAIDA GWAII HOSPITAL	B+	0	0	0	1
NORTHERN HAIDA GWAII HOSPITAL	O-	1	2	0	1
NORTHERN HAIDA GWAII HOSPITAL	O+	1	2	0	2
MERRITT NICOLA VALLEY HEALTH CARE	A-	0	0	0	1
MERRITT NICOLA VALLEY HEALTH CARE	A+	2	3	1	3
MERRITT NICOLA VALLEY HEALTH CARE	AB-	0	0	0	1
MERRITT NICOLA VALLEY HEALTH CARE	AB+	0	0	0	1
MERRITT NICOLA VALLEY HEALTH CARE	B-	0	0	0	1
MERRITT NICOLA VALLEY HEALTH CARE	B+	0	0	0	1
MERRITT NICOLA VALLEY HEALTH CARE	O-	2	3	0	1
MERRITT NICOLA VALLEY HEALTH CARE	O+	2	3	2	5
ARROW LAKES HOSPITAL	A-	1	2	0	1
ARROW LAKES HOSPITAL	A+	1	2	4	6

Hospital Name	Type	Historics	HistoricS	News	New S
ARROW LAKES HOSPITAL	AB-	0	0	0	1
ARROW LAKES HOSPITAL	AB+	0	0	0	1
ARROW LAKES HOSPITAL	B-	0	0	0	1
ARROW LAKES HOSPITAL	B+	1	2	0	2
ARROW LAKES HOSPITAL	O-	1	1	0	1
ARROW LAKES HOSPITAL	O+	2	3	2	4
NANAIMO REGIONAL GENERAL HOSPITAL	A-	10	12	13	14
NANAIMO REGIONAL GENERAL HOSPITAL	A+	46	55	64	67
NANAIMO REGIONAL GENERAL HOSPITAL	AB-	1	2	1	2
NANAIMO REGIONAL GENERAL HOSPITAL	AB+	2	4	5	6
NANAIMO REGIONAL GENERAL HOSPITAL	B-	3	4	3	4
NANAIMO REGIONAL GENERAL HOSPITAL	B+	12	15	16	18
NANAIMO REGIONAL GENERAL HOSPITAL	O-	17	20	14	15
NANAIMO REGIONAL GENERAL HOSPITAL	O+	43	55	52	56
NELSON KOOTENAY LAKE REGIONAL HOSPITAL	A-	1	2	0	2
NELSON KOOTENAY LAKE REGIONAL HOSPITAL	A+	3	4	3	5
NELSON KOOTENAY LAKE REGIONAL HOSPITAL	AB-	0	0	0	1
NELSON KOOTENAY LAKE REGIONAL HOSPITAL	AB+	0	0	0	1
NELSON KOOTENAY LAKE REGIONAL HOSPITAL	B-	1	2	0	1
NELSON KOOTENAY LAKE REGIONAL HOSPITAL	B+	0	0	1	2
NELSON KOOTENAY LAKE REGIONAL HOSPITAL	O-	1	2	1	2
NELSON KOOTENAY LAKE REGIONAL HOSPITAL	O+	3	4	3	5
NEW WESTMINSTER ROYAL COLUMBIAN HOSP.	A-	16	20	16	18
NEW WESTMINSTER ROYAL COLUMBIAN HOSP.	A+	63	80	94	99
NEW WESTMINSTER ROYAL COLUMBIAN HOSP.	AB-	5	6	1	2
NEW WESTMINSTER ROYAL COLUMBIAN HOSP.	AB+	9	12	7	8
NEW WESTMINSTER ROYAL COLUMBIAN HOSP.	B-	13	15	4	5
NEW WESTMINSTER ROYAL COLUMBIAN HOSP.	B+	14	20	22	24
NEW WESTMINSTER ROYAL COLUMBIAN HOSP.	O-	24	30	20	22
NEW WESTMINSTER ROYAL COLUMBIAN HOSP.	O+	61	80	91	96
LIONS GATE HOSPITAL	A-	4	6	3	4
LIONS GATE HOSPITAL	A+	10	16	17	19
LIONS GATE HOSPITAL	AB-	0	0	0	1
LIONS GATE HOSPITAL	AB+	3	4	1	3
LIONS GATE HOSPITAL	B-	1	2	1	2
LIONS GATE HOSPITAL	B+	4	6	5	7
LIONS GATE HOSPITAL	O-	6	8	5	6
LIONS GATE HOSPITAL	O+	14	20	22	24
SOUTH OKANAGAN GENERAL HOSPITAL	A-	1	2	4	5

Hospital Name	Type	Historics	HistoricS	News	New S
SOUTH OKANAGAN GENERAL HOSPITAL	A+	3	4	2	5
SOUTH OKANAGAN GENERAL HOSPITAL	AB-	0	0	0	1
SOUTH OKANAGAN GENERAL HOSPITAL	AB+	0	0	0	1
SOUTH OKANAGAN GENERAL HOSPITAL	B-	0	0	0	1
SOUTH OKANAGAN GENERAL HOSPITAL	B+	1	2	1	2
SOUTH OKANAGAN GENERAL HOSPITAL	O-	2	5	1	2
SOUTH OKANAGAN GENERAL HOSPITAL	O+	3	4	1	4
100 MILE DISTRICT GENERAL	A-	1	2	0	2
100 MILE DISTRICT GENERAL	A+	2	3	3	5
100 MILE DISTRICT GENERAL	AB-	0	0	0	1
100 MILE DISTRICT GENERAL	AB+	0	0	0	1
100 MILE DISTRICT GENERAL	B-	1	2	0	1
100 MILE DISTRICT GENERAL	B+	1	2	1	2
100 MILE DISTRICT GENERAL	O-	2	3	0	1
100 MILE DISTRICT GENERAL	O+	2	3	2	4
PENTICTON REGIONAL HOSPITAL	A-	11	14	6	7
PENTICTON REGIONAL HOSPITAL	A+	17	24	28	31
PENTICTON REGIONAL HOSPITAL	AB-	0	0	0	1
PENTICTON REGIONAL HOSPITAL	AB+	0	0	2	3
PENTICTON REGIONAL HOSPITAL	B-	1	2	1	2
PENTICTON REGIONAL HOSPITAL	B+	4	6	8	9
PENTICTON REGIONAL HOSPITAL	O-	11	14	7	8
PENTICTON REGIONAL HOSPITAL	O+	15	24	23	27
PORT ALBERNI WEST COAST GENERAL HOSPITAL	A-	2	3	1	2
PORT ALBERNI WEST COAST GENERAL HOSPITAL	A+	3	45	67	69
PORT ALBERNI WEST COAST GENERAL HOSPITAL	AB-	1	2	0	1
PORT ALBERNI WEST COAST GENERAL HOSPITAL	AB+	1	2	0	1
PORT ALBERNI WEST COAST GENERAL HOSPITAL	B-	1	2	0	1
PORT ALBERNI WEST COAST GENERAL HOSPITAL	B+	1	2	1	3
PORT ALBERNI WEST COAST GENERAL HOSPITAL	O-	3	4	1	2
PORT ALBERNI WEST COAST GENERAL HOSPITAL	O+	4	6	5	8
PORT HARDY HOSPITAL	A-	1	2	1	2
PORT HARDY HOSPITAL	A+	1	1	0	2
PORT HARDY HOSPITAL	AB-	0	0	0	1
PORT HARDY HOSPITAL	AB+	0	0	0	1
PORT HARDY HOSPITAL	B-	0	0	0	1
PORT HARDY HOSPITAL	B+	1	2	0	1
PORT HARDY HOSPITAL	O-	1	2	0	1
PORT HARDY HOSPITAL	O+	1	2	1	3

Hospital Name	Type	Historic s	Historic S	New s	New S
PORT MCNEILL & DISTRICT HOSPITAL	A-	0	0	0	0
PORT MCNEILL & DISTRICT HOSPITAL	A+	1	2	4	6
PORT MCNEILL & DISTRICT HOSPITAL	AB-	0	0	0	1
PORT MCNEILL & DISTRICT HOSPITAL	AB+	0	0	0	1
PORT MCNEILL & DISTRICT HOSPITAL	B-	0	0	0	1
PORT MCNEILL & DISTRICT HOSPITAL	B+	0	0	0	2
PORT MCNEILL & DISTRICT HOSPITAL	O-	2	3	0	1
PORT MCNEILL & DISTRICT HOSPITAL	O+	2	3	1	4
POWELL RIVER GENERAL HOSPITAL	A-	2	3	1	2
POWELL RIVER GENERAL HOSPITAL	A+	3	4	3	6
POWELL RIVER GENERAL HOSPITAL	AB-	0	0	0	1
POWELL RIVER GENERAL HOSPITAL	AB+	0	0	0	1
POWELL RIVER GENERAL HOSPITAL	B-	1	2	0	1
POWELL RIVER GENERAL HOSPITAL	B+	1	2	1	2
POWELL RIVER GENERAL HOSPITAL	O-	2	3	0	2
POWELL RIVER GENERAL HOSPITAL	O+	4	6	5	7
UNIVERSITY HOSPITAL OF NORTHERN BC	A-	13	15	10	12
UNIVERSITY HOSPITAL OF NORTHERN BC	A+	53	60	65	68
UNIVERSITY HOSPITAL OF NORTHERN BC	AB-	0	0	1	2
UNIVERSITY HOSPITAL OF NORTHERN BC	AB+	5	6	5	6
UNIVERSITY HOSPITAL OF NORTHERN BC	B-	3	4	2	3
UNIVERSITY HOSPITAL OF NORTHERN BC	B+	17	20	15	16
UNIVERSITY HOSPITAL OF NORTHERN BC	O-	17	20	14	15
UNIVERSITY HOSPITAL OF NORTHERN BC	O+	52	60	64	67
PRINCE RUPERT REGIONAL HOSPITAL	A-	1	2	3	4
PRINCE RUPERT REGIONAL HOSPITAL	A+	4	6	4	6
PRINCE RUPERT REGIONAL HOSPITAL	AB-	0	0	0	1
PRINCE RUPERT REGIONAL HOSPITAL	AB+	0	0	1	2
PRINCE RUPERT REGIONAL HOSPITAL	B-	0	0	0	1
PRINCE RUPERT REGIONAL HOSPITAL	B+	1	2	4	5
PRINCE RUPERT REGIONAL HOSPITAL	O-	2	3	0	2
PRINCE RUPERT REGIONAL HOSPITAL	O+	3	4	3	6
PRINCETON REGIONAL HOSPITAL	A-	1	2	0	2
PRINCETON REGIONAL HOSPITAL	A+	2	3	1	2
PRINCETON REGIONAL HOSPITAL	AB-	0	0	0	1
PRINCETON REGIONAL HOSPITAL	AB+	0	0	0	1
PRINCETON REGIONAL HOSPITAL	B-	0	0	0	1
PRINCETON REGIONAL HOSPITAL	B+	0	0	1	2
PRINCETON REGIONAL HOSPITAL	O-	1	2	0	1

Hospital Name	Type	Historic s	Historic S	New s	New S
PRINCETON REGIONAL HOSPITAL	O+	1	2	3	5
QUEEN CHARLOTTE ISLANDS GENERAL HOSPITAL	A-	0	0	0	1
QUEEN CHARLOTTE ISLANDS GENERAL HOSPITAL	A+	1	2	2	4
QUEEN CHARLOTTE ISLANDS GENERAL HOSPITAL	AB-	0	0	0	1
QUEEN CHARLOTTE ISLANDS GENERAL HOSPITAL	AB+	0	0	0	1
QUEEN CHARLOTTE ISLANDS GENERAL HOSPITAL	B-	0	0	0	1
QUEEN CHARLOTTE ISLANDS GENERAL HOSPITAL	B+	0	0	0	1
QUEEN CHARLOTTE ISLANDS GENERAL HOSPITAL	O-	1	2	0	1
QUEEN CHARLOTTE ISLANDS GENERAL HOSPITAL	O+	1	2	0	2
G.R. BAKER MEMORIAL HOSPITAL	A-	2	3	1	2
G.R. BAKER MEMORIAL HOSPITAL	A+	3	4	3	6
G.R. BAKER MEMORIAL HOSPITAL	AB-	0	0	0	1
G.R. BAKER MEMORIAL HOSPITAL	AB+	1	2	0	1
G.R. BAKER MEMORIAL HOSPITAL	B-	1	2	0	1
G.R. BAKER MEMORIAL HOSPITAL	B+	2	3	2	3
G.R. BAKER MEMORIAL HOSPITAL	O-	2	3	1	2
G.R. BAKER MEMORIAL HOSPITAL	O+	4	6	6	8
QUEEN VICTORIA HOSPITAL	A-	1	2	1	2
QUEEN VICTORIA HOSPITAL	A+	1	2	2	4
QUEEN VICTORIA HOSPITAL	AB-	0	0	0	1
QUEEN VICTORIA HOSPITAL	AB+	0	0	0	1
QUEEN VICTORIA HOSPITAL	B-	1	2	0	1
QUEEN VICTORIA HOSPITAL	B+	1	2	1	2
QUEEN VICTORIA HOSPITAL	O-	2	3	0	1
QUEEN VICTORIA HOSPITAL	O+	2	3	3	5
THE RICHMOND HOSPITAL	A-	5	6	7	8
THE RICHMOND HOSPITAL	A+	30	35	48	51
THE RICHMOND HOSPITAL	AB-	3	4	0	1
THE RICHMOND HOSPITAL	AB+	4	6	3	4
THE RICHMOND HOSPITAL	B-	3	4	1	2
THE RICHMOND HOSPITAL	B+	6	10	10	11
THE RICHMOND HOSPITAL	O-	6	8	8	9
THE RICHMOND HOSPITAL	O+	27	35	33	36
SHUSWAP LAKE GENERAL HOSPITAL	A-	1	2	0	2
SHUSWAP LAKE GENERAL HOSPITAL	A+	3	6	6	8
SHUSWAP LAKE GENERAL HOSPITAL	AB-	0	0	0	1
SHUSWAP LAKE GENERAL HOSPITAL	AB+	0	0	0	1
SHUSWAP LAKE GENERAL HOSPITAL	B-	1	2	0	1
SHUSWAP LAKE GENERAL HOSPITAL	B+	1	2	2	3

Hospital Name	Type	Historics	HistoricS	News	New S
SHUSWAP LAKE GENERAL HOSPITAL	O-	6	8	2	3
SHUSWAP LAKE GENERAL HOSPITAL	O+	3	6	6	8
SECHELT ST. MARY'S HOSPITAL	A-	1	2	1	3
SECHELT ST. MARY'S HOSPITAL	A+	4	6	5	7
SECHELT ST. MARY'S HOSPITAL	AB-	0	0	0	1
SECHELT ST. MARY'S HOSPITAL	AB+	0	0	0	1
SECHELT ST. MARY'S HOSPITAL	B-	0	0	0	1
SECHELT ST. MARY'S HOSPITAL	B+	2	3	2	3
SECHELT ST. MARY'S HOSPITAL	O-	3	5	1	3
SECHELT ST. MARY'S HOSPITAL	O+	5	8	6	9
BULKLEY VALLEY DISTRICT HOSP.	A-	1	2	0	2
BULKLEY VALLEY DISTRICT HOSP.	A+	2	3	3	5
BULKLEY VALLEY DISTRICT HOSP.	AB-	0	0	0	1
BULKLEY VALLEY DISTRICT HOSP.	AB+	0	0	0	1
BULKLEY VALLEY DISTRICT HOSP.	B-	0	0	0	1
BULKLEY VALLEY DISTRICT HOSP.	B+	1	2	1	2
BULKLEY VALLEY DISTRICT HOSP.	O-	1	2	0	1
BULKLEY VALLEY DISTRICT HOSP.	O+	2	3	2	4
SQUAMISH GENERAL HOSPITAL	A-	1	2	1	3
SQUAMISH GENERAL HOSPITAL	A+	2	3	2	4
SQUAMISH GENERAL HOSPITAL	AB-	0	0	0	1
SQUAMISH GENERAL HOSPITAL	AB+	0	0	0	1
SQUAMISH GENERAL HOSPITAL	B-	1	2	0	1
SQUAMISH GENERAL HOSPITAL	B+	1	2	2	3
SQUAMISH GENERAL HOSPITAL	O-	2	3	0	1
SQUAMISH GENERAL HOSPITAL	O+	2	3	3	5
SURREY MEMORIAL HOSPITAL	A-	8	10	12	13
SURREY MEMORIAL HOSPITAL	A+	35	45	56	60
SURREY MEMORIAL HOSPITAL	AB-	3	4	1	2
SURREY MEMORIAL HOSPITAL	AB+	2	4	5	6
SURREY MEMORIAL HOSPITAL	B-	5	6	2	3
SURREY MEMORIAL HOSPITAL	B+	15	20	15	16
SURREY MEMORIAL HOSPITAL	O-	9	12	9	10
SURREY MEMORIAL HOSPITAL	O+	33	45	46	49
MILLS MEMORIAL HOSPITAL	A-	2	3	1	2
MILLS MEMORIAL HOSPITAL	A+	3	4	5	7
MILLS MEMORIAL HOSPITAL	AB-	0	0	0	1
MILLS MEMORIAL HOSPITAL	AB+	0	0	0	1
MILLS MEMORIAL HOSPITAL	B-	0	0	0	1

Hospital Name	Type	Historics	HistoricS	News	New S
MILLS MEMORIAL HOSPITAL	B+	1	2	1	2
MILLS MEMORIAL HOSPITAL	O-	2	3	0	2
MILLS MEMORIAL HOSPITAL	O+	3	4	2	4
TOFINO GENERAL HOSPITAL	A-	0	0	0	1
TOFINO GENERAL HOSPITAL	A+	0	0	0	2
TOFINO GENERAL HOSPITAL	AB-	0	0	0	1
TOFINO GENERAL HOSPITAL	AB+	0	0	0	1
TOFINO GENERAL HOSPITAL	B-	0	0	0	1
TOFINO GENERAL HOSPITAL	B+	0	0	0	1
TOFINO GENERAL HOSPITAL	O-	1	2	0	1
TOFINO GENERAL HOSPITAL	O+	1	2	0	2
TRAIL KOOTENAY BOUNDARY REGIONAL HOSP.	A-	2	3	2	3
TRAIL KOOTENAY BOUNDARY REGIONAL HOSP.	A+	5	8	10	12
TRAIL KOOTENAY BOUNDARY REGIONAL HOSP.	AB-	1	2	0	1
TRAIL KOOTENAY BOUNDARY REGIONAL HOSP.	AB+	1	2	0	1
TRAIL KOOTENAY BOUNDARY REGIONAL HOSP.	B-	2	3	0	1
TRAIL KOOTENAY BOUNDARY REGIONAL HOSP.	B+	2	3	2	4
TRAIL KOOTENAY BOUNDARY REGIONAL HOSP.	O-	3	4	1	2
TRAIL KOOTENAY BOUNDARY REGIONAL HOSP.	O+	7	8	7	9
VAN. CHILDREN'S & WOMEN'S HLTH CNR OF BC	A-	4	6	3	5
VAN. CHILDREN'S & WOMEN'S HLTH CNR OF BC	A+	16	20	26	29
VAN. CHILDREN'S & WOMEN'S HLTH CNR OF BC	AB-	1	2	0	1
VAN. CHILDREN'S & WOMEN'S HLTH CNR OF BC	AB+	5	6	4	5
VAN. CHILDREN'S & WOMEN'S HLTH CNR OF BC	B-	1	2	2	3
VAN. CHILDREN'S & WOMEN'S HLTH CNR OF BC	B+	8	10	13	14
VAN. CHILDREN'S & WOMEN'S HLTH CNR OF BC	O-	16	18	11	13
VAN. CHILDREN'S & WOMEN'S HLTH CNR OF BC	O+	16	20	24	26
VANCOUVER ST. PAUL'S HOSPITAL	A-	12	15	15	16
VANCOUVER ST. PAUL'S HOSPITAL	A+	58	70	82	85
VANCOUVER ST. PAUL'S HOSPITAL	AB-	1	2	1	2
VANCOUVER ST. PAUL'S HOSPITAL	AB+	9	12	6	7
VANCOUVER ST. PAUL'S HOSPITAL	B-	4	6	3	4
VANCOUVER ST. PAUL'S HOSPITAL	B+	14	20	19	20
VANCOUVER ST. PAUL'S HOSPITAL	O-	16	20	16	18
VANCOUVER ST. PAUL'S HOSPITAL	O+	57	70	83	87
VANCOUVER GENERAL HOSPITAL	A-	4	8	10	11
VANCOUVER GENERAL HOSPITAL	A+	29	54	60	66
VANCOUVER GENERAL HOSPITAL	AB-	1	2	2	3
VANCOUVER GENERAL HOSPITAL	AB+	2	6	12	13

Hospital Name	Type	Historics	Historic S	News	New S
VANCOUVER GENERAL HOSPITAL	B-	3	6	6	8
VANCOUVER GENERAL HOSPITAL	B+	19	30	37	39
VANCOUVER GENERAL HOSPITAL	O-	28	34	34	36
VANCOUVER GENERAL HOSPITAL	O+	55	86	85	90
ST. JOHN HOSPITAL	A-	0	0	0	0
ST. JOHN HOSPITAL	A+	1	2	2	4
ST. JOHN HOSPITAL	AB-	0	0	0	1
ST. JOHN HOSPITAL	AB+	0	0	0	1
ST. JOHN HOSPITAL	B-	0	0	0	1
ST. JOHN HOSPITAL	B+	0	0	0	1
ST. JOHN HOSPITAL	O-	1	2	0	1
ST. JOHN HOSPITAL	O+	1	2	1	2
VERNON JUBILEE HOSPITAL	A-	8	10	8	9
VERNON JUBILEE HOSPITAL	A+	23	30	27	31
VERNON JUBILEE HOSPITAL	AB-	0	0	0	1
VERNON JUBILEE HOSPITAL	AB+	0	0	3	5
VERNON JUBILEE HOSPITAL	B-	7	8	2	3
VERNON JUBILEE HOSPITAL	B+	6	8	11	13
VERNON JUBILEE HOSPITAL	O-	13	15	10	12
VERNON JUBILEE HOSPITAL	O+	22	30	29	33
VICTORIA ROYAL JUBILEE HOSPITAL	A-	15	21	12	13
VICTORIA ROYAL JUBILEE HOSPITAL	A+	43	60	64	68
VICTORIA ROYAL JUBILEE HOSPITAL	AB-	1	2	1	2
VICTORIA ROYAL JUBILEE HOSPITAL	AB+	2	4	7	8
VICTORIA ROYAL JUBILEE HOSPITAL	B-	4	6	4	5
VICTORIA ROYAL JUBILEE HOSPITAL	B+	6	10	22	24
VICTORIA ROYAL JUBILEE HOSPITAL	O-	24	30	20	22
VICTORIA ROYAL JUBILEE HOSPITAL	O+	41	60	64	69
VICTORIA GENERAL HOSPITAL	A-	8	10	6	7
VICTORIA GENERAL HOSPITAL	A+	24	30	39	42
VICTORIA GENERAL HOSPITAL	AB-	1	2	0	1
VICTORIA GENERAL HOSPITAL	AB+	1	2	3	5
VICTORIA GENERAL HOSPITAL	B-	5	6	2	3
VICTORIA GENERAL HOSPITAL	B+	6	8	11	13
VICTORIA GENERAL HOSPITAL	O-	19	22	11	12
VICTORIA GENERAL HOSPITAL	O+	32	40	40	43
WHISTLER HEALTH CARE CENTRE	A-	0	0	0	1
WHISTLER HEALTH CARE CENTRE	A+	0	0	0	3
WHISTLER HEALTH CARE CENTRE	AB-	0	0	0	1

Hospital Name	Type	Historic s	Historic S	New s	New S
WHISTLER HEALTH CARE CENTRE	AB+	0	0	0	1
WHISTLER HEALTH CARE CENTRE	B-	0	0	0	1
WHISTLER HEALTH CARE CENTRE	B+	0	0	0	1
WHISTLER HEALTH CARE CENTRE	O-	4	6	0	1
WHISTLER HEALTH CARE CENTRE	O+	0	0	0	3
WHITEHORSE GENERAL HOSPITAL	A-	1	2	1	2
WHITEHORSE GENERAL HOSPITAL	A+	2	3	3	5
WHITEHORSE GENERAL HOSPITAL	AB-	1	2	0	1
WHITEHORSE GENERAL HOSPITAL	AB+	1	2	0	1
WHITEHORSE GENERAL HOSPITAL	B-	1	2	0	1
WHITEHORSE GENERAL HOSPITAL	B+	1	2	1	3
WHITEHORSE GENERAL HOSPITAL	O-	2	3	0	2
WHITEHORSE GENERAL HOSPITAL	O+	3	4	3	5
WHITE ROCK PEACE ARCH HOSPITAL	A-	2	4	4	5
WHITE ROCK PEACE ARCH HOSPITAL	A+	17	24	23	25
WHITE ROCK PEACE ARCH HOSPITAL	AB-	1	2	0	1
WHITE ROCK PEACE ARCH HOSPITAL	AB+	1	2	2	3
WHITE ROCK PEACE ARCH HOSPITAL	B-	1	2	1	2
WHITE ROCK PEACE ARCH HOSPITAL	B+	6	8	6	7
WHITE ROCK PEACE ARCH HOSPITAL	O-	4	6	6	7
WHITE ROCK PEACE ARCH HOSPITAL	O+	16	24	22	25
WILLIAMS LAKE CARIBOO MEMORIAL HOSPITAL	A-	2	3	1	2
WILLIAMS LAKE CARIBOO MEMORIAL HOSPITAL	A+	3	4	3	6
WILLIAMS LAKE CARIBOO MEMORIAL HOSPITAL	AB-	0	0	0	1
WILLIAMS LAKE CARIBOO MEMORIAL HOSPITAL	AB+	0	0	0	1
WILLIAMS LAKE CARIBOO MEMORIAL HOSPITAL	B-	1	2	0	1
WILLIAMS LAKE CARIBOO MEMORIAL HOSPITAL	B+	1	2	1	2
WILLIAMS LAKE CARIBOO MEMORIAL HOSPITAL	O-	2	3	1	2
WILLIAMS LAKE CARIBOO MEMORIAL HOSPITAL	O+	3	4	3	6
ABBOTSFORD REG. HOSP. & CANCER CENTRE	A-	7	10	8	10
ABBOTSFORD REG. HOSP. & CANCER CENTRE	A+	40	50	58	62
ABBOTSFORD REG. HOSP. & CANCER CENTRE	AB-	1	2	0	1
ABBOTSFORD REG. HOSP. & CANCER CENTRE	AB+	2	4	4	5
ABBOTSFORD REG. HOSP. & CANCER CENTRE	B-	3	4	2	3
ABBOTSFORD REG. HOSP. & CANCER CENTRE	B+	9	12	12	13
ABBOTSFORD REG. HOSP. & CANCER CENTRE	O-	11	15	10	11
ABBOTSFORD REG. HOSP. & CANCER CENTRE	O+	38	50	49	53

Table C3- List of historic versus new (s, S) for all hospitals and types in BC and Yukon

Appendix D: Simulation Cycle (Blake & Hardy, 2014)

The simulation follows a repeating daily cycle of steps performed at both the supplier and consumers. On each simulated day, the model executes a sequence of calls to the supplier and consumer objects. Each day begins with a call to advance the supplier inventory. This ages the stock on hand at the supplier by one day and causes any stock with zero days of shelf life remaining to be outdated and to leave the system. A call is then made to the supplier object to have inventory arrive. The supplier order is based on a normal approximation to a Poisson distribution with a mean value that is specific to the day of week. The mean value, however, may be adjusted for the supplier's inventory level relative to a target inventory level. The supplier then observes the day's collections, in terms of actual number of units and their blood type, and adds any newly collected units to the testing queue. After receiving units from its own collections process, the supplier object may import additional units from other suppliers.

Once all incoming inventory is in place at the supplier, the simulation loops through each of the consumer objects and makes a call to advance the inventory. As was the case for the supplier, advancing the inventory at the consumer causes the stock on hand to age by one day. Any units with zero days of shelf life remaining are counted as wastage and exit the system. Each consumer object then determines if an order is required. The consumer object evaluates, by blood group and type, its inventory position and compares it to a threshold level. If the current inventory level is less than the threshold level, the consumer issues an order for additional stock to return the inventory to a target level. If any blood group requires replenishment, the consumer issues an order to bring all blood groups up to their target levels. Consumer orders are aggregated by blood group and compared to available inventory. If available inventory is sufficient to meet all consumer requests, the supplier fills orders in decreasing order of consumer size as measured by average daily demand. If inventory is insufficient to meet all consumer requests, each individual order is prorated by (units available / units requested) before being filled by the supplier, again in decreasing order of average daily demand. Available units are then released from inventory and dispatched to consumers.

To simulate demand for product, a call is made to each consumer object. Daily demand at consumer sites is assumed to be Poisson distributed with a mean value that is specific to the day of the week. Once total demand is determined, each demand item is assigned a blood group. Demand is filled FIFO from available units on the shelf. If no units are available, compatible units may be substituted. If no exact or compatible unit is available, the consumer site issues a demand for additional units, on an emergency basis, from the supplier. If available, emergency units are transferred with zero delay to the consumer object, using the same logic as regular demand. The supplier may substitute a compatible unit, if no exact match is available. If no compatible unit is available, the demand is considered to be lost. Once all demand from consumer sites has been met, the supplier may export units to other distribution centres, using logic similar to that for imports. The simulated day then ends and statistics are collected about inventory, wastage, arrivals, demand, and shortages. The statistical counters are reset and the daily cycle begins again.

At the end of each replication, a statistics collection routine is executed to summarize the daily simulation results. When all replications are complete, a final collection routine is executed to summarize results across all replications and to output the results to the application summary database.

Appendix E: Supplier warm-up Period, Based on Welch Method in the Newfoundland and Labrador Centre

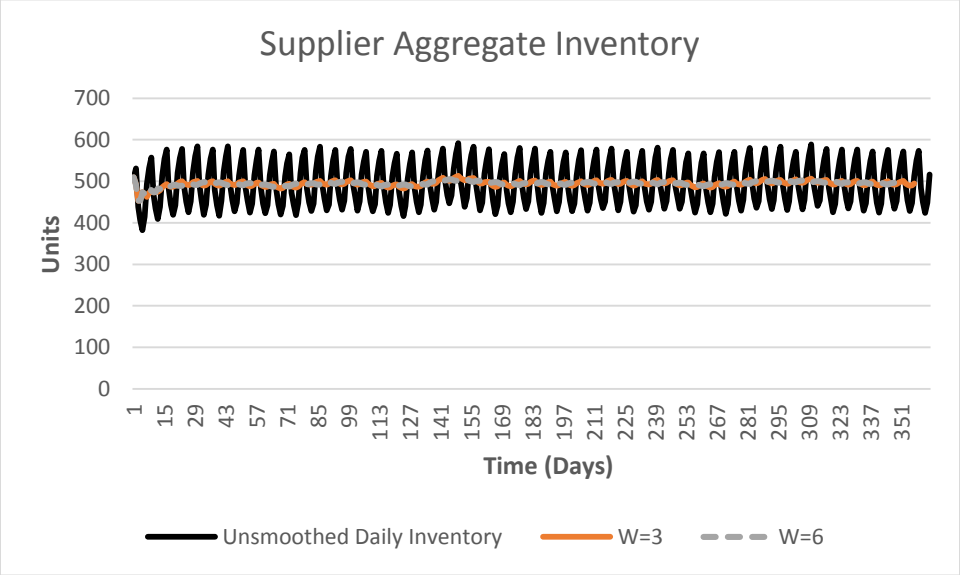

Figure E1- Graph depicting supplier aggregate inventory in the Newfoundland centre, used for confirming warm-up period of 42 days based on Welch method (W=3 and W=6)

Appendix F: One-Sided t-tests for Metrics of Interest in all Centres

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	28.01	5.75	12.27	3.32	1.00
A+	148.69	195.12	38.15	37.74	0.00
AB-	5.48	0.58	1.40	0.09	1.00
AB+	35.15	6.09	2.49	2.51	1.00
B-	8.47	1.77	3.50	0.74	1.00
B+	93.42	21.76	5.02	10.52	1.00
O-	39.25	13.78	20.83	6.39	1.00
O+	130.95	255.96	45.26	40.63	0.00

Table F1- Statistical test to compare the baseline supplier inventory mean against the new scenario supplier inventory mean in the Newfoundland centre. All results are statistically significant at the α = 5% level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.37	0.27	0.09	0.05	1.00
A+	0.41	0.65	0.15	0.15	0.00
AB-	0.10	0.10	0.03	0.02	0.55
AB+	0.20	0.23	0.01	0.04	0.00
B-	0.03	0.16	0.02	0.02	0.00
B+	0.09	0.33	0.02	0.09	0.00
O-	0.12	0.14	0.04	0.04	0.03
O+	0.15	0.39	0.05	0.11	0.00

Table F2- Statistical test to compare the baseline hospital wastage mean against the new scenario hospital wastage mean in the Newfoundland centre. All values are significantly different except in instances where the p-value (highlighted) is between 0.025 and 0.975.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.02	0.01	0.03	0.02	0.90
A+	0.00	0.00	0.01	0.00	0.84
AB-	0.01	0.00	0.01	0.00	1.00
AB+	0.00	0.00	0.00	0.00	0.00
B-	0.02	0.00	0.01	0.01	1.00
B+	0.00	0.00	0.00	0.00	0.00
O-	0.03	0.09	0.04	0.07	0.00

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
O+	0.00	0.00	0.01	0.00	0.87

Table F3- Statistical test to compare the baseline hospital shortage mean against the new scenario hospital shortage mean in the Newfoundland centre. All values are significantly different except in instances where the p-value (highlighted) is between 0.025 and 0.975.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.11	0.07	0.06	0.05	0.99
A+	0.11	0.00	0.03	0.00	1.00
AB-	0.08	0.00	0.01	0.00	1.00
AB+	0.00	0.00	0.00	0.00	1.00
B-	0.12	0.02	0.02	0.01	1.00
B+	0.02	0.00	0.01	0.00	1.00
O-	0.10	0.20	0.05	0.10	0.00
O+	0.05	0.01	0.02	0.01	1.00

Table F4- Statistical test to compare the baseline hospital emergency order mean against the new scenario hospital emergency order mean in the Newfoundland centre. All results are statistically significant at the $\alpha = 5\%$ level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	100.27	68.99	44.67	32.14	1.00
A+	547.91	1308.68	136.24	99.78	0.00
AB-	20.01	2.64	11.93	0.45	1.00
AB+	191.7	22.78	6.05	11.28	1.00
B-	34.15	2.98	23.43	0.96	1.00
B+	390.02	182.00	13.71	42.62	1.00
O-	128.70	36.34	88.80	21.03	1.00
O+	735.41	505.35	147.66	91.55	1.00

Table F5- Statistical test to compare the baseline supplier inventory mean against the new scenario supplier inventory mean in the Ottawa centre. All results are statistically significant at the $\alpha = 5\%$ level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.08	0.42	0.02	0.06	0.00
A+	0.12	1.83	0.04	0.18	0.00
AB-	0.06	0.35	0.04	0.04	0.00
AB+	0.00	0.62	0.00	0.07	0.00
B-	0.05	0.42	0.04	0.05	0.00
B+	0.07	0.73	0.02	0.08	0.00

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
O-	0.38	0.28	0.08	0.08	1.00
O+	0.32	2.46	0.04	0.04	0.00

Table F6- Statistical test to compare the baseline hospital wastage mean against the new scenario hospital wastage mean in the Ottawa centre All results are statistically significant at the $\alpha = 5\%$ level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.04	0.02	0.10	0.02	0.87
A+	0.00	0.00	0.00	0.00	0.00
AB-	0.04	0.00	0.05	0.00	1.00
AB+	0.00	0.00	0.00	0.00	0.00
B-	0.05	0.00	0.06	0.00	1.00
B+	0.00	0.00	0.00	0.00	0.00
O-	0.01	0.16	0.02	0.10	0.00
O+	0.00	0.00	0.00	0.00	0.00

Table F7- Statistical test to compare the baseline hospital shortage mean against the new scenario hospital shortage mean in the Ottawa centre. All values are significantly different except in instances where the p-value (highlighted) is between 0.025 and 0.975.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.56	0.26	0.11	0.15	1.00
A+	0.56	0.11	0.03	0.02	1.00
AB-	0.15	0.01	0.06	0.01	1.00
AB+	0.64	0.00	0.04	0.00	1.00
B-	0.41	0.06	0.04	0.05	1.00
B+	0.77	0.02	0.05	0.01	1.00
O-	0.19	0.55	0.03	0.44	0.00
O+	0.39	0.08	0.05	0.02	1.00

Table F8- Statistical test to compare the baseline hospital emergency order mean against the new scenario hospital emergency order mean in the Ottawa centre. All values are statistically significant at the $\alpha = 5\%$ level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	114.65	43.66	57.19	29.07	1.00
A+	743.98	1208.14	140.96	149.07	0.00
AB-	13.79	3.25	10.65	0.64	1.00
AB+	180.86	44.09	42.58	16.61	1.00
B-	26.48	6.65	16.28	2.78	1.00
B+	332.69	85.28	57.06	21.22	1.00
O-	241.67	72.68	98.74	36.41	1.00
O+	1324.99	1518.29	149.96	126.26	0.00

Table F9- Statistical test to compare the baseline supplier inventory mean against the new scenario supplier inventory mean in the BC and Yukon centre. All results are statistically significant at the $\alpha = 5\%$ level.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.30	0.66	0.09	0.10	0.00
A+	0.73	1.28	0.08	0.10	0.00
AB-	0.18	0.41	0.08	0.06	0.00
AB+	0.45	0.65	0.13	0.13	0.00
B-	0.29	0.38	0.08	0.09	0.00
B+	0.25	0.26	0.03	0.06	0.14
O-	0.17	0.13	0.09	0.05	0.96
O+	0.10	0.04	0.03	0.02	1.00

Table F10- Statistical test to compare the baseline hospital wastage mean against the new scenario supplier hospital wastage in the BC and Yukon centre. All values are significantly different except in instances where the p-value (highlighted) is between 0.025 and 0.975.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.04	0.05	0.07	0.03	0.30
A+	0.00	0.00	0.00	0.00	0.00
AB-	0.1	0.00	0.06	0.00	1.00
AB+	0.00	0.00	0.00	0.00	0.00
B-	0.07	0.01	0.07	0.01	1.00
B+	0.00	0.00	0.00	0.00	0.00
O-	0.00	0.33	0.02	0.22	0.00
O+	0.00	0.00	0.00	0.00	0.00

Table F11- Statistical test to compare the baseline hospital shortage mean against the new scenario hospital shortage mean in the BC and Yukon centre. All values are significantly different except in instances where the p-value (highlighted) is between 0.025 and 0.975.

Type	Mean Baseline	Mean New Policy	σ Baseline	σ New Policy	p-Value
A-	0.24	0.38	0.13	0.14	0.00
A+	0.55	0.70	0.05	0.03	0.00
AB-	0.38	0.02	0.17	0.01	1.00
AB+	0.32	0.05	0.04	0.01	1.00
B-	0.27	0.18	0.25	0.07	0.98
B+	0.14	0.19	0.02	0.03	0.00
O-	0.52	1.13	0.04	0.39	0.00
O+	0.93	1.52	0.07	0.09	0.00

Table F12- Statistical test to compare the baseline hospital emergency order mean against the new scenario hospital emergency order mean in the BC and Yukon centre. All results are statistically significant at the $\alpha = 5\%$ level