Multivariate analysis of exogenous variables for blood donation system in some European countries – logistics approach

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Abstract
Effective blood donation system is paramount to national health security. It is subject to research conducted both by medical and logistics experts (services). The aim of this paper is to employ multivariate statistical analysis to assess the functioning blood donation system and risk analysis in this study area. Utilised for purposes of this paper were methods of multivariate data mining to study of blood donation system activities in selected European countries (in the European Union).

Key Words: blood donation, multivariate statistical analysis, logistics, risk analysis

Introduction

Availability of blood and its components used for medical purposes due to the fact, they could not be synthetically produced, is contingent on willingness of citizens of a given country to donate. This is the underlying principle of blood donation. Moreover, according to European Union policy, Member States are obliged manage their blood reserves in a way that would make them self-sufficient. Therefore, the demand for blood and its components has to be catered for by its domestic supply. In light of the above, Member States ought to develop a fully-fledged and efficient blood donation system on their territory. Based on observation, blood donation system could be divided into civil and for uniformed services. Also, from another angle: public, private and mixed (combination of the two). Obtaining the blood from donors is, however, the first necessary step in the entire process of blood management. Apart from processing and preservation processes, management decisions are made concerning its storage, location of storage place as well as distribution criteria for passing it to health care facilities, where blood, as medication, is it supposed to be used to the benefit of patients. By competently managing its resources, a blood donation system is also ought to mitigate the risk of blood and its components shortage at any given time in any given place. In order to resolve some of the problems related to low blood availability, logistics solutions could be employed. Bearing in mind the rationale underlying management decisions and the overarching priorities, one of three main types of logistics should be used in role of initial template for further deliberations - social logistics; Szołtysek and Trzpiot (2012).

Social logistics perspective in managing blood reserves

Social logistics is efficient management of material flows (and associated information) which are socially valuable, in order to create particular spacetime values (and complementary goods) which are needed by the society and assure its well-being; Szołtysek (2010). Hence, deliberations of logistics nature are based on perception of blood management issues in the context of material flows of blood and its components and any related information, which is subject to processing and modification - due to managerial actions - in order to achieve the predetermined goal of blood donation system i.e. saving health and lives by supplying blood and its components within the blood supply chain creating a blood supply system. The above view reflects the paradigm of logistics; Szołtysek (2012). Each chain has its first and last link. In case of material flow of blood and its components, first and last link are stochastic. Therefore, the institutions (actors) taking part in blood flow are supposed to balance system entry with exit. Blood supply chains in institutional dimension include blood donor and recipient, institution and organisation, which take part in blood flow from obtaining the blood to transfusion (Hospital). At each stage of the process, a particular predefined need should be provided for. From logistics point of view, correct blood (type) in due time, place and form (packaging, temperature, expiration date, description) as well as amount has to be supplied to the end recipient. So, logistics is supposed to assure availability. In Poland, however, there are problems with initialising flow of blood and its components. The stipulation that a domestic blood supply chain; Twaróg (2012) has to be fully self-sufficiency means that its success depends to a significant extent on donors and their willingness to donate blood in given amounts, time and place; Ojrzyńska and Twaróg (2012).

Issues with initiating blood flows potentially damaging to the system

Problems with initiating flows of blood and its components within the system and could jeopardise its efficiency may divided by risk categories: Organisational, Health and Psychological. Generally speaking, the main risk innate to blood supply chain is the mismatch between location and time of where the blood is donated and required. It may be defined as loss of liquidity is supplies of blood and its components. Depending on risk categories, numerous factors could be identified. And so, the following factors concern organisational risk: untimely, incomplete supplies of blood and its components, loss of quality during technological processing, incorrect blood type labelling, equipment malfunctions. Factors related to health risks are e.g.: diseases decreasing the number of donors complying with required health standards, unplanned circumstances barring particular donors from giving blood (increasing number of tattoos, piercing or other forms of body art). On the other hand, perception that blood donating is not safe is one of the factors describing the psychological risk (religious views, rumours and opinions that blood donating may be addictive (blood overproduction), pain related to giving blood). Given the above, the following research problems were defined: 1) How risks related to above factors could be mitigated? 2) Is it possible to use benchmarking in order to decrease the number of identified factors? To address the issues, statistical methods of multivariate data exploration were employed to analyse blood donation systems in EU Member States.

Research methodology

Efficiency of blood donation system in any given country could be objectively assessed using multivariate data analysis. This paper presents how taxonomic measure of investment attractiveness (TMAI) was used to shortlist EU countries where blood donation systems are most safe and efficient from the viewpoint of risk per number of donors; Tarczyński and Mojsiewicz (2001). The measure is defined as:

$$TMAI_i = 1 - \frac{di}{d_0} \tag{1}$$

where:

$TMAI_i$ - synthetic measure of development for i-th object

d_i - distance of i-th object from model object given by:

$$d_i = \sqrt{\sum_{j=1}^{m} w_j (z_{ij} - z_{0j})^2} \quad (i = 1,2,...,n) \tag{2}$$

d_0 - standard for $TMAI_i$ to take values between 0 and 1;

$$d_0 = \overline{d} + 2 \cdot S_d \tag{3}$$

Weights w_j were assigned based on coefficient of variation of variable (V_j) - the higher the coefficient of variation, the higher the weight:

$$w_j = \frac{V_j}{\sum_{j=1}^{m} V_j} \tag{4}$$

This paper uses Hellwig's method of linear ordering to select EU countries with best efficiency and safety from the viewpoint of risk per number of blood donors (number of blood donations). Hellwig's method allows to create a "ranking" of objects in terms of several variables. Objects are ordered based on their distance between a given object and the reference object. Coordinates of the reference object were determined objectively using the formula:

$$w_{0j} = \begin{cases} \max_i \{z_{ij}\} & \text{for stimulants} \\ \min_i \{z_{ij}\} & \text{for destimulants} \end{cases} \quad (5)$$

where:
w_{oj} - reference for j-th variable,
z_{ij} – variable value for i-th object and j-th variable.
Hellwig's method of linear ordering orders objects based on Euclidean distance of i-th object from the reference object:

$$d_{i0} = \sqrt{\sum_j \left(z_{ij} - w_{oj}\right)^2} \quad (6)$$

The closer Hellwig's measure to one, the closer is analysed object from the reference object. Another multivariate method used for the research was clustering based on agglomeration algorithm, collecting objects into increasing clusters, using a measure of similarity and distance. One of clustering methods is hierarchical cluster analysis. It may be characterised as follows. Let us consider a matrix of object distances. An assumption is made each object is a different class. At each stage several classes are found with a minimum distance allowing to cluster them together. Then the distance between the new cluster and other is determined. This algorithm is repeated until all classes are clustered into one. The difference between variants of agglomeration method comes down to how distance between clusters is determined. There are several standard clustering algorithms such as single linkage, complete linkage, average linkage, the Ward's method.This paper uses the hierarchical cluster analysis. Hierarchical cluster analysis enables creating classes of objects similar in terms of several variables, based on the distance matrix. Distances were determined using the Ward's method, where dissimilarity between clusters is defined as average root mean square of distances between class' centres on mass (lack-of-fit sum of squares):

$$d_{AB} = \frac{n_A n_B}{n_A + n_B} d^2\left(\bar{x}_A, \bar{x}_b\right) \quad (7)$$

The result of the method is dendrogram i.e. binary class tree, where clusters are represented by the nodes, whereas leafs are classifiable objects. An optimum number of clusters returns highest ratio of between-groups variance and within-group variance. That criterion is referred to as the Calinski and Harabasz Index:

$$CH(k) = \frac{tr(M)/(k-1)}{tr(W)/(n-k)} \quad (8)$$

One-dimensional description of blood donation in EU Member States

Based on 2009 research Eurobarometr, one-dimensional analysis of blood donation system in EU Member States was carried out first. Thirty seven percent of EU citizens declared they have donated blood. The majority of donors were men (44 per 100 men) compared to women (31 per 100 women). The most numerous age group was 40 to 52 years old, as opposed to least numerous 15 to 24 (fig. 1). Structure of blood donors by profession and education was presented in fig. 2 and 3. The highest percentage of people who have donated blood was among those was completed their education at an age of at least 20. The lower percentage of blood donors was among people still in education. In terms of professions, the most prone to donate blood were managers, self-employed and labourers.

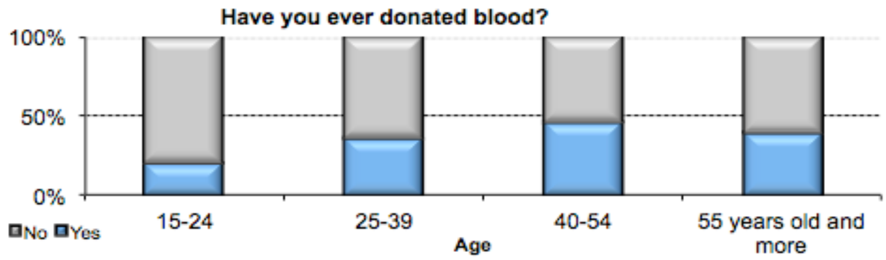

Fig. 1. Structure of blood donors in EU by age

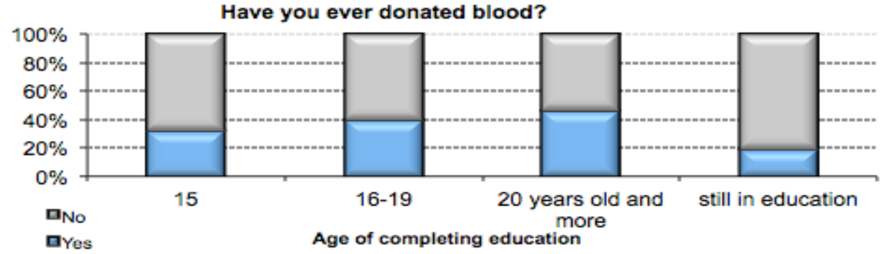

Fig. 2. Structure of blood donors in EU by education

Fig. 3. Structure of blood donors in EU by profession

The area of the European Union, however, is diversified in terms of the number of people who have ever donated blood as per fig. 4.

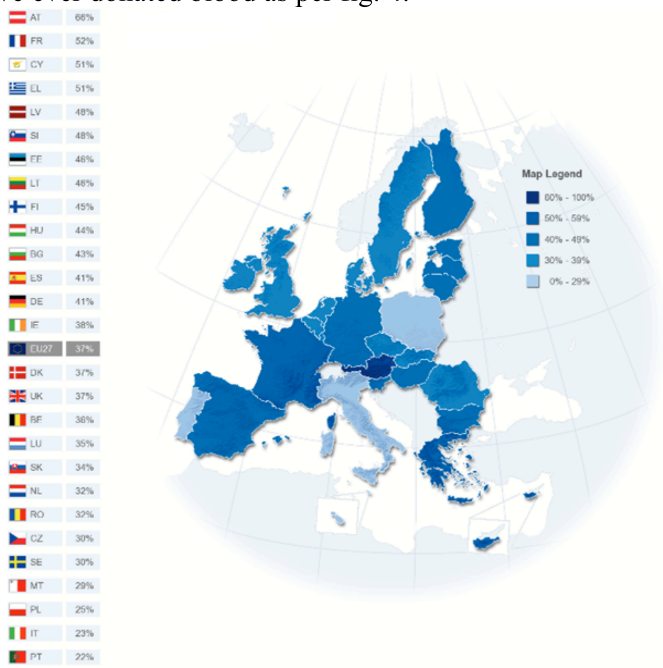

Fig. 4. Ex post supply in blood donation systems in different EU countries

Source: Blood donation and blood transfusion, Special Eurobarometer 333 b, TNS Opinion & Social, Belgium 2010, p. 10.

Among countries with the highest percentage of blood donors are: Austria (66%), France (52%), Greece and Cyprus (51%). Among new entrants to the EU and Eastern European countries: Bulgaria, Estonia, Latvia, Lithuania, Hungary and Slovenia the percentage of people donating blood was higher than EU average. On the other hand, the lowest percentage of people declaring they have donated blood was in Portugal (22%), Italy (23%), Poland (25%) and Malta (29%).

Multivariate description of blood donation in EU Member States

In this part of the paper, EU Member States were classified by the following metrics: 1) number of donors per 1000 citizens between 2001 and 2008; 2) percentage of people declaring they have donated blood; 3) percentage of people deeming blood donating safer in 2009 than it was 10 years ago or equally as safe; 4) percentage of people deeming blood donating less safe in 2009 than it was 10 years ago.

Hierarchical cluster analysis was employed: Ward's and complete linkage methods. Similar classifications were obtained using above methods based on Euclidean distance. Consequently, seven clusters of countries were formed (dendrogram for Ward's method is illustrated in fig. 5).

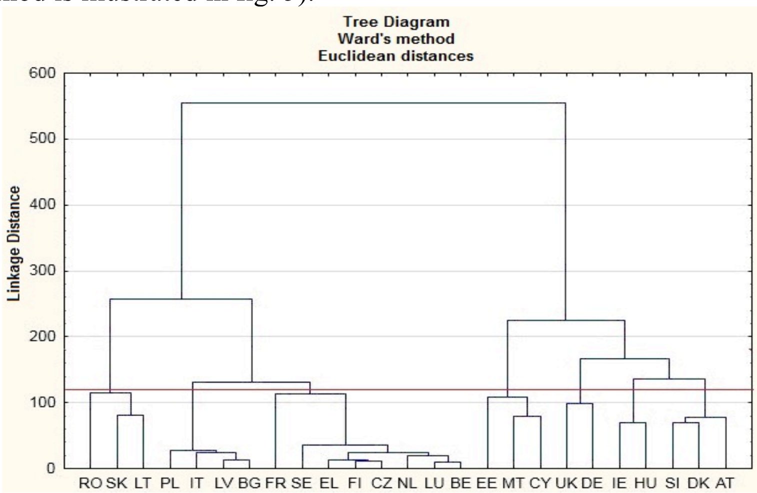

Fig. 5. Dendrogram of EU countries based on Ward's method with split

Cluster 1 includes countries: Romania, Slovenia, Lithuania. In this group the number of blood donors per 1000 citizens is low and only 70% of surveyed citizens held opinion that blood transfusion is safe or equally as safe as in the past decade. Cluster 2 consists of Poland, Italy, Latvia, Bulgaria and also shows a low number of blood donors, however, the level of trust towards blood transfusions is greater than in case of cluster one. Third cluster contains: France, Sweden, Greece, Finland, Czech Republic, Holland, Luxembourg and Belgium. The number of blood donors is average, but the percentage of people thinking blood transfusion is safer than or just as safe as 10 years ago is high. The next cluster of countries shows high number of blood donors. It includes: Estonia, Malta, Cyprus. The following cluster: Great Britain and Germany represents an average number of blood donors and average trust among citizens towards blood transfusion. Cluster 5 contains Ireland and Hungary, where an average number of donors may be a consequence of low trust towards safety of blood transfusion. The last cluster includes: Slovenia, Denmark and Austria. Those are the countries with the highest percentage of blood donors and the highest fraction of people perceiving blood transfusion as safer than it was 10 years ago. Hellwig's method was employed to select countries showing the highest efficiency and safety of the blood donation system from the viewpoint of the number of donors. The following three metrics were used for that study:

- stimulants: a) number of donors per 1000 citizens between 2001 and 2008; b) percentage of people declaring they have donated blood; c) percentage of people deeming blood donating safer in 2009 than it was 10 years ago or equally as safe;
- destimulants: a) percentage of people deeming blood donating less safe in 2009 than it was 10 years ago;

a ranking was created of countries with best and worst blood donation system (fig. 6).

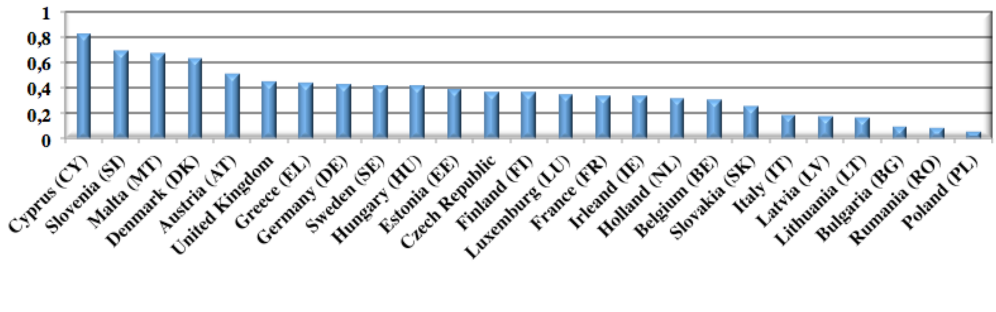

Fig. 6. Blood donation in European Union - risk of losing liquidity of blood and its components supplies - TMIA

Among countries with the best situation i.e. exposed to the lowest risk related to time and location disparities impacting supplies of blood and its components (liquidity loss of blood supplies) are: Cyprus, Slovenia, Malta, Denmark and Austria. Whereas countries carrying much greater risk are Poland, Romania, Bulgaria, Lithuania and Latvia.

Summary

The success of Polish blood donation system, similarly to other European Union countries is contingent on donor willingness to donate blood at the right time, place in the right quantity and quality. Poland performs rather badly in terms of the number of blood donors per 100 citizens. Identified risks are predominantly related to circumstances in which flows of blood are initiated in the system. Each EU country undergoing temporary difficulties with blood supplies develops its own methods to activate donors, which fit current economic, legal and cultural conditions or reaches out to other countries for solutions. If correctly selected, those methods decrease the probability of disrupted supply of blood and its components in the system (mitigate consequences of the risk). Presented in this paper methods of multivariate data analysis (factoring in multi-thread and multi-faceted nature of blood donation situation) may be used for benchmarking which helps identifying similar countries using praiseworthy systems to draw from. Similarities were searched for in: 1) situation of blood donation in terms of supplying blood and its components, 2) human behaviours expressed as willingness to donate blood (ex ante supply) or resulting in blood donation (ex post supply), destimulants - negative perception of blood transfusion safety. In order to make the blood donation system successful (and mitigate consequences of identified risks), each EU Member State is recommended to select a country for benchmarking purposes i.e. a "role model".

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