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DETERMINANTS OF BLOOD SUPPLY CHAINS IN POLAND

Abstract. The objective of this paper is to present the main factors determining the blood supply chains in Poland and to show similarities and differences between the provinces in terms of blood donation. This work identifies provinces with "better" and "worse" situation in blood donation. This paper is the first stage of an attempt to describe the optimal blood demand structure in Poland.

Key words: multivariate analysis, logistics, blood supply chain, blood supply chain determiners.

I. INTRODUCTION

From the dawn of history saving human life depended on the application of appropriate medicines and the ability of the right choice was perceived as the art. Blood was and still is one of the medications saving human's life. Blood produced by living beings is considered to be unique, precious, impossible to imitate, create, copy or substitute with any another thing or medicine, and from the perspective of a logistic researcher – a resource. Despite such a long human history and unrelenting attempts to produce an artificial blood, a human has not achieved this until today.

II. BLOOD AND ITS CHARECTIRICTICS

Blood is a whole world of its own. Its components (which can be divided into haematogenous[1] and plasma preparation[2]) create highly developed immune

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[1] Haematogenous preparations are: whole undiluted blood, erythrocyte concentrate, platelet (thrombocyte) concentrate, white blood cell; leucocyte a. leukocyte concentrate, granulocyte concentrate and fresh frozen plasma, in: T.F. Krzemiński *Farmakologia farmakoterapia oraz materiały stosowane w stomatologii*, Katowice-Warszawa, 2003, pp. 359.

and transport system, which our life and health depend on. One of the characteristics of human blood is its serologic diversity – varieties, groups. It can be one of the group A, B, AB or 0. Apart from a blood group a human can have in their blood cells of the antigen Rh+ (about 85% of human population) – and then such blood is described as Rh positive. Remaining 15% of people do not have this antigen – then such blood is described as Rh negative[3]. The percentage representation of each blood group in Polish population is shown in the Picture 1. According to the Main Statistical Office data Poland is inhabited by 38135876 persons[4], whereof: 12203480 inhabitants have A Rh (+) blood group, 11822122 – 0 Rh (+), 5720381 – B Rh (+), 2669511 – AB Rh (+), 2288153 – A Rh (-), 2288153 – 0 Rh (-), 762718 – B Rh(-) and 381358 persons with the rarest group – AB Rh (-). Under some circumstances some of the blood groups can be exchanged (Picture 2) what creates a true challenge for people responsible for blood management in Poland (people employed in the Public Blood Service Units in Poland[5]) and for logistic managers managing supply chains and storage.

Picture 1. Percentage share of blood groups in Poland

Donor

Receiver	0-	0+	B-	B+	A-	A+	AB-	AB+
AB+	YES	YES	YES	YES	YES	YES	YES	YES
AB-	YES	NO	YES	NO	YES	NO	YES	NO
A+	YES	YES	NO	NO	YES	YES	NO	NO
A-	YES	NO	NO	NO	YES	NO	NO	NO
B+	YES	YES	YES	YES	NO	NO	NO	NO
B-	YES	NO	YES	NO	NO	NO	NO	NO
0+	YES	YES	NO	NO	NO	NO	NO	NO
0-	YES	NO	NO	NO	NO	NO	NO	NO

Picture 2. Blood group compatibility

Source: Regional Blood Donor and Haematherapy Centre Source: National Blood Centrehttp://www.rckikwarszawa.com.pl/dlakr_krew.html http://www.nck.gov.pl/index.php?page=krew6

[2] plasma preparations: albumin, VIII agent concentrate and immunoglobulin-specific, in: T.F. Krzemiński *Farmakologia farmakoterapia oraz materiały stosowane w stomatologii*, Katowice- Warszawa, 2003, pp.359.

[3] Characteristics of human blood: http://www.rckik-katowice.com.pl/rola.html

[4] Main Statistical Office, Population. Condition and Structure In Territorial Cross section. State at 31 December 2008, Warszawa 2009, pp.359

[5] In Poland the Public Blood Service Units are: Research Institute, Regional Blood Donor and Haematherapy Centers (Regionalne Centra Krwiodawstwa I Krwiolecznictwa RCKiK), Military Blood Donor and Haematherapy Centers (Wojskowe Centrum Krwiodawstwa I Krwiolecznictwa) and Blood Donor and Haematherapy Center (Centrum Krwiodawstwa I Krwiolecznictwa) created by the proper ministry of the Home Office (the Bill 22 August 1997, *The Public Blood Service,* Law Journal dated 11 September 1997 – article 4.3). In some countries (for example German-speaking countries: Austria, Germany, Switzerland) a private blood service is in operation: Verband unabhängiger Blutspendedienste e. V. - http://www.vubd.org

Whole undiluted blood[6] is used after accidents and in emergency cases: haemorrhaging with a loss of over 25% of blood in a short period of time, an exchange transfusion for newborn babies. When there is no time for blood testing then an universal group 0 Rh (-) is used, as patient's side effects risk is smaller.

III. BLOOD DISTRIBUTION CHAIN

Everyday practice of blood and / or haematogenous products management faces with many difficulties which blood service workers try to solve. This what happens to blood from the very moment of donation to the moment of transfusion lies at heart of the logistics, which can suggest a set of tools for the material- and information - flow management. These flows are realised in the form of typical supply chains, which consist of a donor and a blood recipient, institutions and organisations which participate in the blood flow processing and storage from the moment of donation to transfusion. As a consequence of realising of these flows defined needs should be met and optimalized. In each case it is required that blood gained from a donor, after essential processing, is supplied according to the logistic philosophy, in order to despatch, the right blood in the right quantity and the right condition, to the right place, at the right time with maintaining the strict storage and distribution conditions, which, in turn, guarantee the required standard of service. The process of blood supply flow between a donor and a recipient can be shown in *the form of limited number of variants* of supply chains[7] (an example of the longest blood supply chain – Picture3). Logistic managers who look for possible areas of improvements try to answer the following questions: what is the optimal way of managing blood supplies, which optimality tags are to be defined / created and how to treat blood resources from the point of financial value or as merchandise.

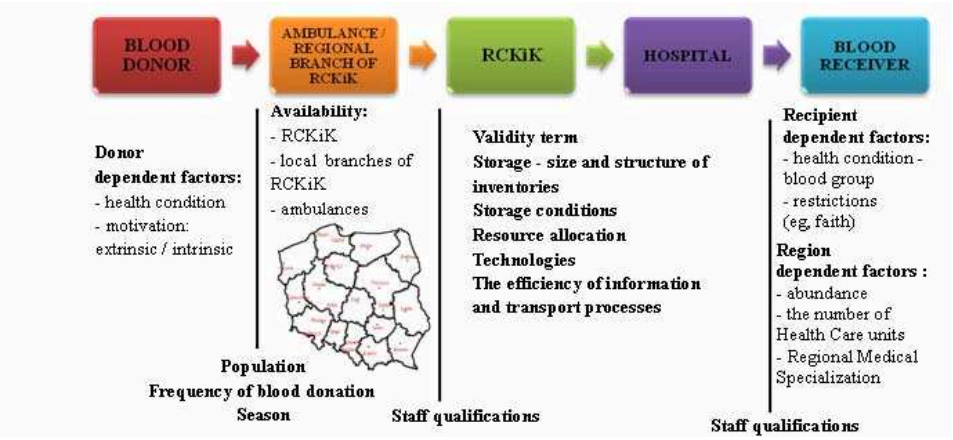
[6] Whole undiluted blood transfusion is uneconomical, it is connected with not fully utilizing its components, with a higher risk of complications and higher probability of transferring infectious diseases. That is why according to current trends the rule " transfuse a patient only what they need" is commonly applied.

[7] Cooperating public blood service organizational units as well as blood donors and receivers, between whom the flows of blood and / or haematogenous products and connected information are realized, are called blood supply chains. See: Szołtysek J., Twaróg S., *Gospodarowanie zasobami krwi jako nowy obszar stosowania logistyki,* Gospodarka Materiałowa i Logistyka Nr 7/2009

Picture 3. Blood supply chain – participants (the longest chain)

Source: Szołtysek J., Twaróg S., *Gospodarowanie zasobami krwi jako nowy obszar stosowania logistyki,* Gospodarka Materiałowa i Logistyka Nr 7/2009

Determinant (Latin: *determinantis* – restrictive, defining) every factor used to define (determine) something.[8] Blood supply chains depend on determinants affecting them – this relation is presented in Picture 4. The main factors are: health condition, extrinsic (benefits) and intrinsic motivation (idea), frequency of blood donation (it depends on season). All countries in the World have problem with blood availability during holiday season, because blood donation decreases. Really important is availability of: Regional's Blood Donor and Haematherapy Centers, regional branches and ambulances. Equally important is validity term, method of blood storage and resources allocation.



Picture 4. Determinants of blood supply chains

Source: own resource.

[8] Słownik Wyrazów Obcych (1993), PWE, Warszawa, pp. 185

IV. MULTIVARIATE STATISTICAL METHODS

Application of multivariate statistical methods for blood supply chains in Poland allowed to present the current blood donation in a territorial layout and define determiners shaping blood supply chains. Hellwig's method, hierarchical cluster analysis, multivariate scaling, correlation and regression analyses have been used. Hellwig's linear ordering method allows to create "rating" of objects described by few variables. Ordering of objects is based on the distances between an object and an object-pattern. The coordinates of the pattern are defined objectively according to the formula:

$$w_{0j} = \begin{cases} \max\limits_{i}\{z_{ij}\} \text{ for stimulants} \\ \min\limits_{i}\{z_{ij}\} \text{ for destimulants} \end{cases} \tag{1}$$

w_{oj} – pattern for *j*-th variable
z_{ij} – value of variable for *i*-th object and *j-th* variables.

Hellwig's measure orders objects based on the Euclidean distance of *i*-th object from a pattern object. The closer to unity Hellwig's measure, the closer *i*-th object to the pattern is.

$$d_{i0} = \sqrt{\sum_{j}\left(z_{ij} - w_{oj}\right)^2} \tag{2}$$

Hierarchical cluster analysis allows to create the class of objects similar to each another with regard to a few variables based on a distances matrix. The distances were defined on the basis of Ward's method, where dissimilarities among objects are defined as an average of distance square of class gravity centre:

$$d_{AB} = \frac{n_A n_B}{n_A + n_B} d^2\left(\overline{x}_A, \overline{x}_b\right) \tag{3}$$

The result of the method application is a dendogram which is a binary tree, where nodes represent the cluster whereas the leaves classified objects. The optimal number of created clusters gives the highest ratio of intergroup variance to intragroup variance. This criterion is known as Celinski and Harabasz Index:

$$CH(k) = \frac{tr(M)/(k-1)}{tr(W)/(n-k)} \tag{4}$$

The multivariate scaling reduces the space of many variables to two- or three- dimensions. Reduced space will be defined by the described variables which have the strongest correlation with the newly created dimensions. Such mapping is sought where the value of STRESS matching function reaches the minimum:

$$S^2 = \frac{\sum \left(d_{ik} - \hat{d}_{ik}\right)^2}{\sum d_{ik}^2} \tag{5}$$

$\hat{d}_{ik}$ - regressive function between d_{ik} and δ_{ik},

d_{ik} - distance between *i* and *k* object in the reduced space,

δ_{ik} - distance between *i* and *k* object in the non-reduced space.

The correlation and regression analyses allow to determine significance of influence of one variable over the other one. The significance test for the linear Pearson correlation coefficient and regression model parameters allow to define which independent variables significantly influence on dependent variable. The measure of the matching model quality to empirical data is a determination coefficient – value close to unity proves of high model quality:

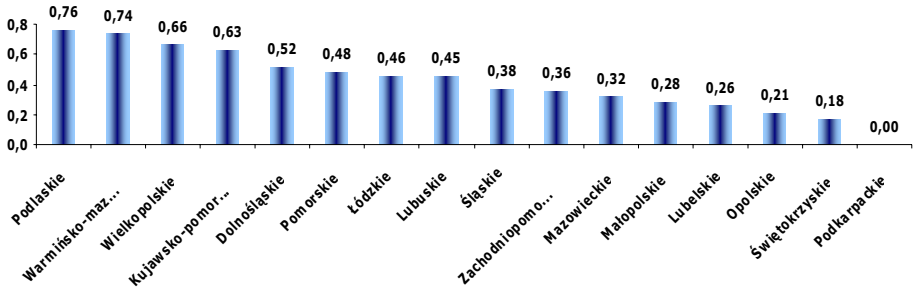
$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2} \tag{6}$$

V. ANALYSIS OF BLOOD DONATION SITUATION AND FACTORS INFLUENCE ON BLOOD SUPPLY CHAINS IN POLAND

A multivariable statistical analysis is based on a set of six variables with a normal distribution, for which variation coefficients are equal from 16% to 59%. The variables describing particular provinces presented the number of inhabitants per: one donor, a regional branch, a blood ambulance crew, a hospital, a unit of whole undiluted blood,[9] a unit of haematogenous preparations. All variables are destimulants – the higher variable value, the less favourable situation in a province is.

[9] Whole undiluted blood unit contains 450 ml (+/– 10%).

Hellwig's method allowed to order the provinces with the least and the most favourable blood donation situation.



Picture 5. Presentation of ranking from "the best" to "the worst" province in terms of blood donation - Hellwig's measure

Source: own research.

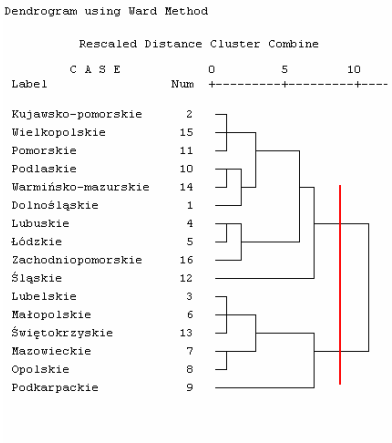
The highest value of Hellwig's measure has Podlaskie province – the province has the most favourable situation regarding the six variables that were included in the analysis. Table 1 presents detailed data for the three provinces with the least and the most favourable situation in Poland.

Table 1. Three provinces with the most and the least favourable situation in blood donation

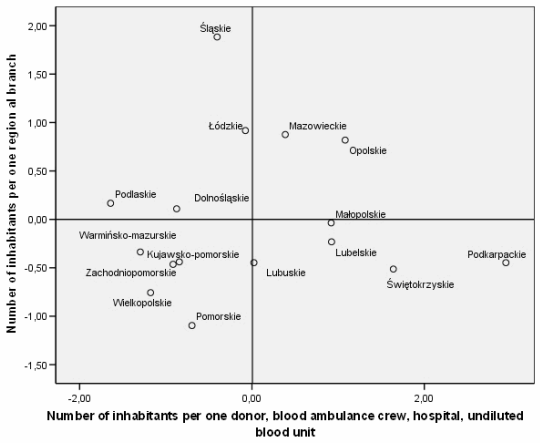
Province	1. Podlaskie	2. Warmińsko-mazurskie	3. Wielkopolskie	14. Opolskie	15. Świętokrzyskie	16. Podkarpackie
Number of inhabitants per one donor	51	62	54	88	80	104
Number of inhabitants per one regional branch	198 578	142 707	161 791	258 260	181 826	233 277
Number of inhabitants per one blood ambulance crew	2 878	4 222	4 833	4 612	8 212	13 997
Number of inhabitants per one hospital	42 553	41 973	53 930	51 652	63 639	67 726
Number of inhabitants per one whole undiluted blood unit	34	35	33	48	50	52
Number of inhabitants per one haematogenous preparations unit	30	33	31	46	49	52

Source: own research.

Hierarchical cluster analysis allowed to create two classes. This is an optimal number of clusters regarding the maximal value of Calinski and Harabasz Index. The cluster of the most advantageous situation includes 10 provinces (Picture 6) and 6 provinces with the least favourable blood donation situation. In order to present the similarities among the provinces the multivariable scaling method was applied. The Picture 7 – map of perception – III quarter of coordinate system presents the provinces with the most favourable situation and the similarities among them regarding to two dimensions.



Picture 6. Dendrogram divides Poland to two groups: provinces with "better" and "worse" situation in terms of blood donation



Picture 7. Perception map presents links between provinces in terms of blood donation situation

Source: own research.

Relevant determinants shaping blood supply chains in Poland are presented in the Picture 4. In this chapter the authors distinguished the key determinants. The significance test of the Pearson coefficient presented one significant factor (significance level = 0.01) which influences on the blood supply chain in Poland – the number of inhabitants per one donor.

Table 3. Influence of factors on blood supply chain in Poland

Pearson Correlation	Number of inhabitants per one whole undiluted blood unit	Number of inhabitants per one haematogenous preparations unit
Number of inhabitants per one donor	**0.87**	**0.87**
Number of inhabitants per one regional branch	0.24	0.12
Number of inhabitants per one ambulance	0.49	0.55
Number of inhabitants per one hospital	0.47	0.51

Source: own research.

The regression analysis allowed to determine detailed influence of a significant determinant on the blood supply chain in Poland. Two models of high determination coefficients ($R^2 = 76\%$) defining the correlation between the number of inhabitants per a donor and a number of inhabitants per one whole undiluted blood unit (Model I: $y = 11,98 + 0,42x$) and whole undiluted blood along the components (Model II: $y = 8,03 + 0,44x$). In both models it is right to state that a decline by a unit of number of inhabitants per one donor will increase the waiting line for a blood unit by about half a person. Authors are aware of the fact that these are not all determinants which influence the shape and structure of blood supply chains.

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DETERMINANTY W ŁAŃCUCHU DOSTAW KRWI W POLSCE

Celem pracy jest określenie kluczowych czynników kształtujących łańcuch dostaw krwi w Polsce. Przeprowadzona wstępna analiza danych z wykorzystaniem wielowymiarowych metod statystycznych pozwoli zobrazować obecną sytuację polskiego krwiodawstwa w układzie terytorialnym. Praca jest pierwszym etapem zmierzającym do określenia optymalnego zapotrzebowania krwi w Polsce.