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# KRIs IN HOSPITALS – NETWORK, CORRELATIONS AND INFLUENCES

**Abstract.** *After 1990, the Romanian health system has entered into a comprehensive reform process, which continues even today in order to meet the conditions imposed by the European Union. Also, the implementation of a risk management's system in each hospital is a condition that has to be accomplished and implemented. As the risks encountered at a hospital's level can be taken from a whole array of possible risks, in this paper, ten of the most influencing risks have been depicted in order to be analysed. Using NodeXL, these risks have been drawn along with their inter-connections and their influences have been determined. Knowing these aspects will allow the hospital's management to properly handle their occurrence.*

***Key words:*** *hospital, key risk indicators, management, risk, network.*

**JEL Classification: C53, I10, M14.**

## 1. Introduction:

In the recent years, it has been given an increased prominent to the concept of clinical governance, as a method to provide the best quality of healthcare in a complex adaptive system. Risk management is essential for successful clinical governance, especially because of the analysis conducted for identifying the causes that lead to an adverse event, a risk. In the medical field, the risk management represents all the processes in which is identified, analyzed, mitigated, or avoided a risk that may affect the financial condition of a hospital or of the health professionals [**Project Management Institute, 2004**].

The risks that are affecting a hospital are often determined by multiple causes. We meet very often correlated risks that affect in chain several departments of a hospital. Early identification of risks that may adversely affect a hospital is essential, of utmost importance being also the determination of how those risks affect the appearance of other risks, creating an avalanche phenomenon.

Given this, it is necessary to establish a set of key risk indicators (KRI), which are measurable metrics capable of gathering the level of risk exposure and losses encountered in a hospital. That is why, for each risk that can affect a hospital is assigned a KRI, which is used as an early warning system, that provide a forward direction, more reliable information about the risk. As the hospital faces more risks, the risk exposure is increasing, causing the hospital's vulnerability. Also, in this case, the losses generated by the occurrence of the adverse event become significant.

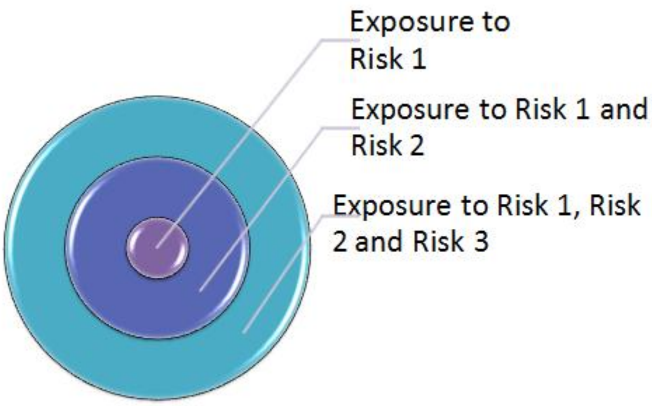



**Figure 1. Multi-level risk exposure**

## 2. The hospital - a complex adaptive system

Currently, we assist to the development of several disciplines that have emerged from the General Theory of Systems and Cybernetics, such as: genetic algorithms (Holland), artificial intelligence (Simon and Newell), systems dynamics (Forrester), synergetics (Hoken), theory of catastrophes (Thom), the fuzzy systems theory (Zadeh), A-Life (Langhton), autopoiesis (H. Maturana and F. Varela), evolutionary biology (Darwin), self-organized criticality (Per Bak and Tang Chao), fractal geometry (Mandelbrot), the theory of boolean networks (St. Kaufmann), the chaos theory (Edward Lorenz) etc.. These disciplines are summarized in Complexity Science, whose object of study is the complex adaptive system (CAS). There have been offered numerous definitions for complex adaptive system over time, but at this point the most relevant definition is considered to be the one of

Professor Eve Mitleton-Kelly, the director of the Complexity Research Programme at the London School of Economics.

According to this definition, any CAS is defined by the following ten general characteristics:**[Mitleton-Kelly E., 2003**]

1. self-organisation
2. emergence
3. connectivity and interdependence
4. feedback
5. far from equilibrium
6. space of possibilities
7. co-evolution
8. historicity & time
9. path-dependence
10. creation of new order

Let's see in the following, why the hospital is a CAS and how this can influence the way we are modelling it. First of all, we shall check if it succeeds to incorporate all of these ten characteristics.

In terms of self-organization, emergence and creation of a new order, it can be very easily observed that each of these characteristics can be encountered in a hospital. For example: the spontaneous order that arises when a subsystem of the hospital, a department, the medical staff, or the hospital in ensemble respond to environmental incentives, represent the self-organisation. From here, the emergence of the processes that creates a new order is strictly related to the self-organisation one.

The emerging phenomenon is met whenever new ideas and collaborative relationships occur between the staff of a hospital. The results of teamwork are the new knowledge gained through interaction between team members. The development of knowledge in a particular medical problem imprints itself certain behaviour related to the treatment of the problem, and thus arrive an evolution, a new order.

In a hospital, connectivity and interdependence accrues from the fact that any medical or management decision that leads to a particular action, affects in different extents all the agents that compose the system (hospital), whether they are medical staff, managers, patients, or a specific department.

Co-evolution can be very well observed in a department's evolution when a doctor's knowledge is highly positively connected with the knowledge and interactions with and between other doctors - each agent influences and is influenced.

Far from equilibrium, path dependence and historicity are three other key features of every complex adaptive system. In a hospital, every doctor is choosing from several possible alternatives of treatment for a patient, and the patients are choosing from more alternatives whenever they have the opportunity, this causing a certain evolutionary path for each of them. Therefore, the evolution of each patient's health depends on choices, choices related to history.

When treating a patient, each doctor must choose a strategy from an array of possible strategies and he must choose a treatment considering all the symptoms. But, when the symptoms change, the chosen treatment cannot be considered anymore suitable. In this case, for curing patients it is necessary to continually monitor the symptoms and to choose another best regimen, which is, in fact, the exploration of the space of possibilities.

Finally, when speaking about the feedback, the simplest example comes into our minds. The feedback can be reflected by the influence on the regimen to the patient's treatment response and on the future evolution of the disease. We get positive feedback when the patient responds well to treatment and his condition is improving, causing the doctor to continue with the same treatment. If the doctor is faced with negative feedback, then he tends to lose motivation and to seek alternatives to treat the disease.

## 3. Creating a set of Key Risk Indicators (KRIs) for the risk analysis of a hospital

The hospital is a complex environment faced with many risks both internal and external, risks that may affect both patients and medical staff.

The hospital risk management targets the measures that must be taken in order to mitigate or to avoid an adverse event. When patient safety is at stake, then we talk about safe and risk management (SRM). SRM manages the safety incidents, medical errors and expected risks. [**Dückers M., Faber M., Cruijsberg J., Grol R., Schoonhoven L., Wensing M., 2009**]

Key risk indicators are used as an early warning system for determining the direction of where the risk comes from, the level of the risk, and the deviation from the objectives set by the hospital managers. KRIs is the foundation of an effective risk management, so it is necessary to create an effective set of KRIs.

Any set of key risk indicators should be established by persons with expertise in the field, who know very well the operations that take place in each department. When an indicator is chosen, it must be very close of the risk cause. Continuous monitoring of the indicators and informing the management when the value of KRIs does not fit into the accepted interval is mandatory.

The hospital is a complex adaptive system, and that is why, the risk analysis is important. The complexity is shown by the numerous risks that threaten the welfare of the healthcare institution and by the paths by which the exposures are propagated.

Next, we will analyze 10 risks that may adversely affect the smooth running of a hospital. The first indicator is the loss of Government Funding. In Romania, the public hospitals are the majority; the number of private hospitals representing only 20% of the total. Thus, it can be easily noticed that the functioning of the health system depends largely on money from the budget, and a poor financial situation of the state can be a bottleneck for hospitals. Lack of medicines in hospitals and non-payment of medical staff are just two examples of the negative consequences of this risk event.

The Clinical risk represents: "*the probability that a patient suffer harm or distress, even involuntary, attributable to the care received during hospitalization, extending the duration of hospitalization, worsening the health state, or causing the death of the patient".* **[Tereanu C., 2010]** The manifestation of clinical risk attracts complaints from patients, lawsuits and relevant financial loss.

Hospitals are required to operate medical education and research for doctors, nurses and other staff. This can be done by creating research centres in various medical fields, journals and applying projects that are funded by the State or the European Union. Through the research and innovation activity is developed a research and concern culture for the exploitation of the research results in the benefit of human health. Lack of concern for research may be a sign of doctor's superficiality and can affect their value.

Information privacy and cyber-security are hotspots for any medical institution, the vulnerability in this area being able to lead to leakage of sensitive information. New technologies in the field of medical care are not adequately designed to protect the patient from possible data theft. Network and database protection of viruses and malware should represent for any hospital risk management a priority.

Natural disaster risk has a low probability of occurrence, but a terrible impact on any hospital. Failure of infrastructure, insufficient numbers of medical staff and available beds and outdated equipment creates a nightmare scenario.

Poor technology limits the diagnostic and treatment process of patients. Romania faces, after 20 years from revolution, with hospitals that don't have necessary equipment, numerous surgeries and medical procedures being performed only at hospitals in big cities. That risk is directly correlated with the risk of inability to engage patients.

The biggest problem that currently affects the medical system is the overseas exodus of valuable doctors (blocking positions in hospitals and low wages are the main causes). Physician's relationships are important to the quality of care provided by a hospital. Creating teams focused primarily on quality and performance improvement initiatives offers favourable climate for innovation and new knowledge.

| No. | Type of risk | Key Risk Indicator |
|---|---|---|
| 1. | loss of government funding | - the actual government funding/ the government funding from last year |
| 2. | lack of research | - Number of articles published and projects carried out by the medical staff of the hospital |
| 3. | information privacy and cyber-security | - No. days of system downtime |
| 4. | natural disasters | - No. temporary hospital beds / total no. hospital beds;<br>- No. medical specialties available on-call time<br>- No. average patient / anesthesia and intensive care physician; |
| 5. | poor technology | - Technology update rate |
| 6. | inability to engage patients | - No. nurses / shift on call;<br>- Average bed occupancy rate in the wards;<br>- Average waiting time from presentation to the emergency room till meeting with doctor |
| 7. | clinical risks | - Number of complaints |
| 8. | regulatory issues | - Number of warnings and fines received |
| 9. | The loss of the valuable medical staff | - The concordance index between the admission diagnosis and the diagnosis after 72 hours;<br>- Number of medical staff that have left the country |
| 10. | physicians relationships | - Number of team's projects in the last year |

**Table 1. Type of risks and KRIs encountered in hospitals**

## 4. Correlated risks. Building a risk network using NodeXL

A network is a collection of nodes or vertices which are connected by edges. From the atomic to the planetary level are encountered natural and artificial systems that form networks. The study of networks started in 1735, when Euler solved the famous problem of Könisberg's bridges, leading to the development of the modern theory of graphs.

In the following, we will create a network using the risks presented in the previous chapter. The vertices will represent the identified risks; and the edges will illustrate the correlation that exists between two risks. When the manifestation of a risk can cause a chain occurrence of other risks, we will notice more edges starting from that risk to other risks that are being influenced by it. The label which is retrieved on each edge represents the probability of risk occurrence.

To create the network and calculate the associated indicators we use NodeXL. This is an open source software, a template for Microsoft Excel 2007, dedicated for network analysis and visualization. It allows: „*a variety of visual properties, supports powerful filtering, calculates frequently used network metrics, and offers rich support for diverse visual network layouts*". [**Hansen D.L., Shneiderman B., Smith M.A., 2011**]

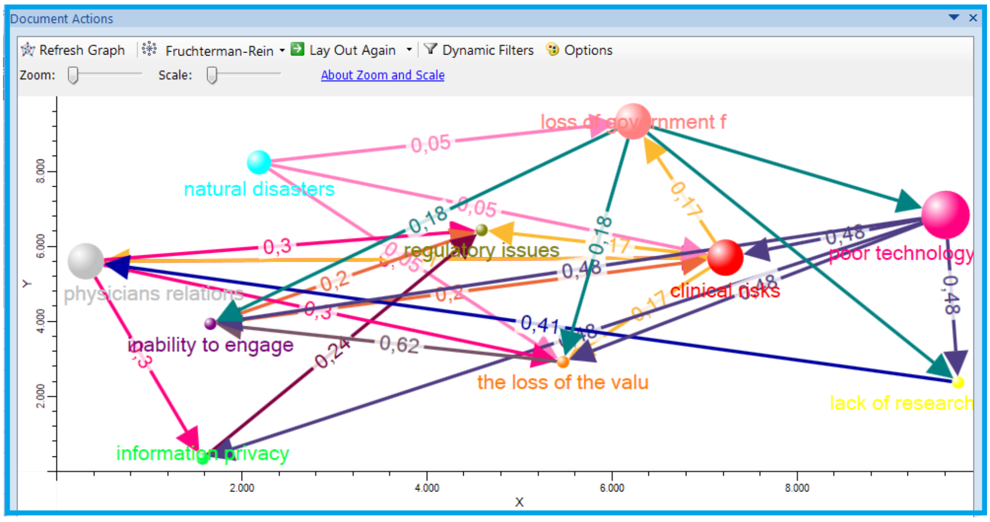



**Figure 2. The risk's network**

NodeXL automatically computes 7 vertex-specific networks metrics. Network analysis allows the observation and study of the patterns found in the connected risks. This analysis is based on the relational databases, on the degree to which a risk influences the occurrence of other risks. We can divide the 10 identified risks into two categories:

- the infectious risks, that have connections with many others;
- the influence risks, that are connected with few risks, but they have many links.

If risks are in one category or another, it can be inferred from the degree indicator. The degree of a vertex in a network is given by the number of its edges.

Betweenness centrality is a metric of how often a vertex is found on the shortest path between two other vertices. Closeness centrality represents the average distance between a vertex and every other vertex in the network. A risk with few connections could have a very high eigenvector centrality if those few connections were themselves very well connected (the influence risks).

The network analysis can be achieved at macroscopic or microscopic level. The measures calculated in this table illustrate at a microscopic level the role of the vertices. For instance, the clinical risk has the highest degree. This means that the manifestation of this risk influences eight other appearances of risks. The hospital will face a cascading risks and managing them will be extremely difficult. On the opposite side are two other risks: natural disasters and information privacy and cyber-security.

| | Graph Metrics | | | | | | |
|---|---|---|---|---|---|---|---|
| Vertex | Degr | Degre e | Out-Degree | Betweenness Centrality | Closeness Centrality | Eigenvector Centrality | Clustering Coefficient |
| loss of government funding | 6 | 2 | 4 | 0,632 | 1,333 | 0,381 | 0,300 |
| lack of research | 3 | 2 | 1 | 0,123 | 1,667 | 0,198 | 0,167 |
| information privacy and cyber-security | 3 | 2 | 1 | 0,123 | 1,778 | 0,170 | 0,167 |
| natural disasters | 3 | 0 | 3 | 0,000 | 1,778 | 0,232 | 0,500 |
| poor technology | 6 | 1 | 5 | 0,947 | 1,333 | 0,371 | 0,233 |
| inability to engage patients | 5 | 3 | 2 | 0,246 | 1,444 | 0,349 | 0,350 |
| clinical risks | 8 | 4 | 4 | 1,000 | 1,222 | 0,432 | 0,262 |
| the loss of the valuable medical staff | 6 | 5 | 1 | 0,509 | 1,333 | 0,393 | 0,333 |
| physicians relationships | 6 | 2 | 4 | 0,772 | 1,444 | 0,276 | 0,150 |
| regulatory issues | 4 | 4 | 0 | 0,281 | 1,556 | 0,237 | 0,333 |

**Figure 3. Graph metrics**

Regarding the betweenness centrality indicator, the highest value is recorded by clinical risks. According to this value, there is no manifestation of the one of the $10^{th}$ risks that are analyzed, that influences the occurrence of another risk and do not influence the occurrence of clinical risk. The values of this indicator are the percentage of the frequency of occurrence of a risk in the road made by contagion generated by another risk. The values computed are between 12 % and 100 %.

The closeness centrality registers values between 1.222 and 1.778. The lower values indicate a more central position in the network. A value of 1.222 means that the associated risk is directly connected to many risks, it influences the manifestation of the most risks in the network. However, the risks associated to vertices situated in peripheral locations will have a high value of this indicator, reflecting the number of risks that need to influence to mark the emergence of the furthest risk in the network.

The eigenvector centrality indicates the risks that affect the appearance of the most contagious risks. It reflects the production of significant losses, even if at first glance the risk does not directly influence the expression of many other risks. It can be easily seen that the hospital must avoid the appearance of: clinical risk, the loss of the valuable medical staff and the loss of the government funding.

The next figure illustrates the clusters which are automatically identified in the network created by NodeXL. The clusters are indicated by the vertex's colour and shape, all the vertices in one cluster having the same colour. There were identified three clusters, whose nodes have the following colours: green, yellow and red. Clusters are groups of densely connected vertices that are weak connected to other groups.

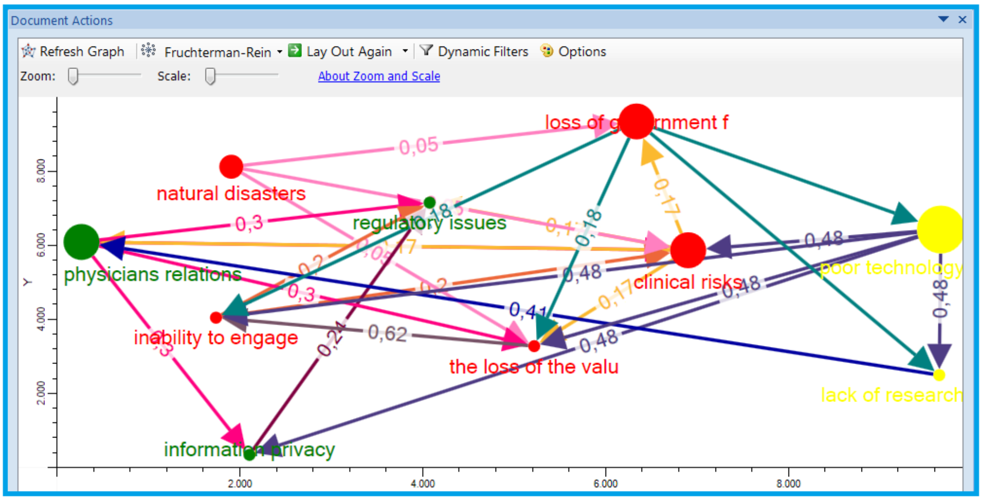
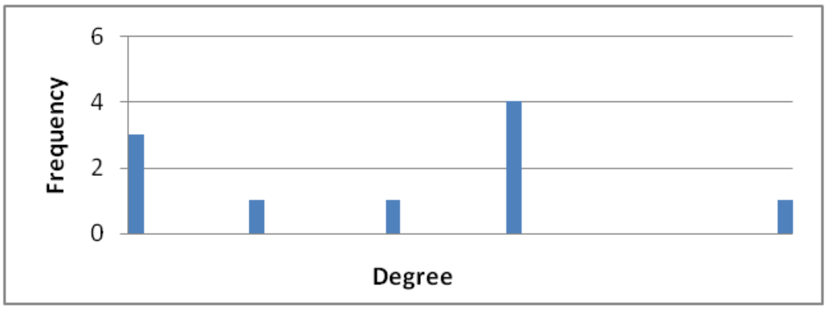



**Figure 4. Network clusters**

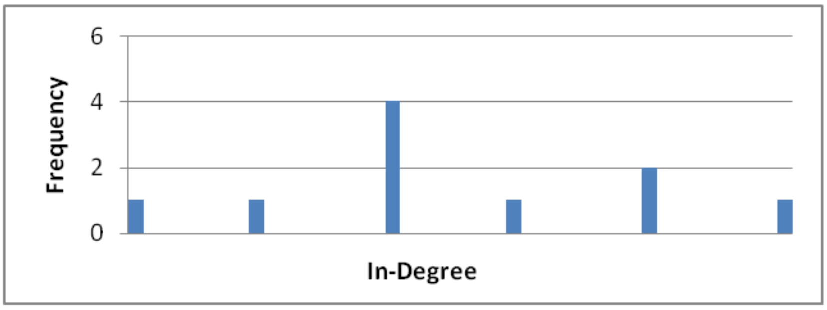
It might be observed that natural disasters, loss of government funding, clinical risks, inability to engage patients and the loss of valuable medical staff are forming the biggest cluster. The following table shows the most important indicators for the entire network and their related values.

| Metric | Value |
|---|---|
| Graph Type | Directed |
| | |
| Vertices | 10 |
| | |
| Unique Edges | 25 |
| Edges With Duplicates | 0 |
| Total Edges | 25 |
| | |
| Self-Loops | 0 |
| | |
| Connected Components | 1 |
| Single-Vertex Connected Components | 0 |
| Maximum Vertices in a Connected Component | 10 |
| Maximum Edges in a Connected Component | 25 |
| | |
| Maximum Geodesic Distance (Diameter) | 3 |
| Average Geodesic Distance | 1,49 |
| | |
| Graph Density | 0,28 |
| | |
| NodeXL Version | 1.0.1.113 |

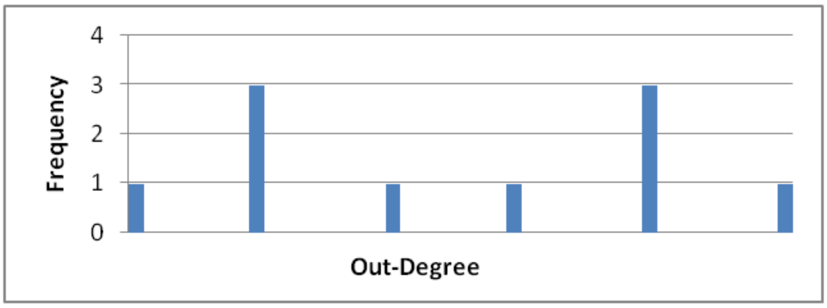
**Table 2. Metrics' values**



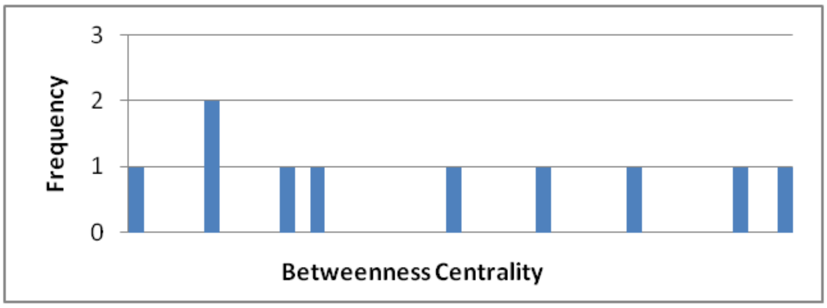

| | |
|---|---|
| Minimum Degree | 3 |
| Maximum Degree | 8 |
| Average Degree | 5,00 |
| Median Degree | 5,50 |



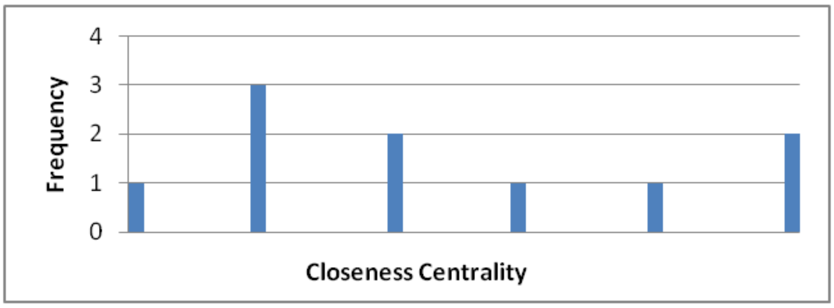

| | |
|---|---|
| Minimum In-Degree | 0 |
| Maximum In-Degree | 5 |
| Average In-Degree | 2,50 |
| Median In-Degree | 2,00 |



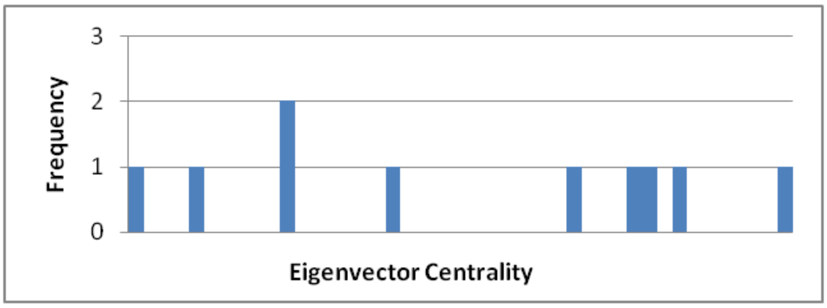

| | |
|---|---|
| Minimum Out-Degree | 0 |
| Maximum Out-Degree | 5 |
| Average Out-Degree | 2,50 |
| Median Out-Degree | 2,50 |



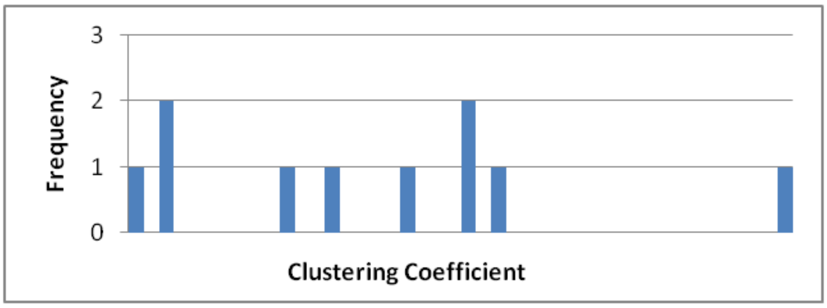
| | |
|---|---|
| Minimum Betweenness Centrality | 0 |
| Maximum Betweenness Centrality | 1 |
| Average Betweenness Centrality | 0,46 |
| Median Betweenness Centrality | 0,39 |




| | |
|---|---|
| Minimum Closeness Centrality | 1,222222222 |
| Maximum Closeness Centrality | 1,777777778 |
| Average Closeness Centrality | 1,49 |
| Median Closeness Centrality | 1,44 |




| | |
|---|---|
| Minimum Eigenvector Centrality | 0,170119108 |
| Maximum Eigenvector Centrality | 0,431527434 |
| Average Eigenvector Centrality | 0,30 |
| Median Eigenvector Centrality | 0,31 |




| | |
|---|---|
| Minimum Clustering Coefficient | 0,15 |
| Maximum Clustering Coefficient | 0,5 |
| Average Clustering Coefficient | 0,28 |
| Median Clustering Coefficient | 0,28 |

**Table 3. The metrics and their frequency of occurrence computed by NodeXL**

At a macroscopic level of network analysis, the focus is on the statistical characterization of the network. The geodesic distance represents the length of the shortest way between two risks. It reflects the number of risks the initial risk must infect to get from one risk to another. The maximum geodesic distance is three and the average value for all the risks is 1.49.

The density of the network measures how many edges are in the network compared to the maximum possible number of edges. It can be seen that the network created is not very dense, the number of correlations between risk reaching only the value of 0.28.

## 5. Conclusions:

Hospital Risk Management is the authority that deals with uncertainty, represents all the processes in which is identified, analyzed, mitigated, or avoided a risk that may affect the financial situation of the healthcare institution.

Creating and implementing a suitable set of key risk indicators may represents for a hospital the required steps to successfully manage its exposures to complex risks. The risks are often correlated, producing adverse effects in chain. Creation, analysis and simulation of a network that includes risks that may affect the hospital is an important step in managing risks. Network analysis provides powerful ways to summarize networks and identify key risks or other problems that represent strategic positions within the matrix of connections. The hospital's risk network analysis provides management an advantage to study, compare and react to changes that occur in the hospital's exposure to risk and trend of a particular type of risk.

The network's metrics computed by NodeXL represents properties of any complex network, with their help being described the connection's forms between parts of the network's risks.

Note: the order of the authors on this paper is random, their contribution to the achieved results being equal.

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