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Using network methodology to define emergency response team location: The Brazilian refinery case study

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ABSTRACT: The main objective of this study is to define Emergency Response Team Location in a specific area based on the risk of plants and facilities. The Center of Gravity and Haikini Network methodologies are the two different approaches used to define the location in a network based on index values and distance between locations. These methodologies are different in regard to one basic concept concerning the possibility of defining critical locations in the network in the first case and their boundaries in the second case. The index in this case will be the frequency of hazardous events in each facility or plant located in the network.

The two methodologies will be implemented and the results will be assessed. Therefore, a sensitivity analysis will be carried out looking at specific elements such as alternative routes and population dislocation in the case of accidents. Furthermore, the real historical data and the usual data used in Brazil in hazardous event will be assessed to check the influence on final results.

The refinery case study will be carried out to define the Emergency Response Team location in a Brazilian refinery.

1 INTRODUCTION

Network methodologies involve different approaches to solving different logistical problems, such as minimizing product flow, defining the best routes to different customer locations, etc.

The Center of Gravity methodology has been long used in physics and mathematics for resolving problems and is now used to provide logistical decisions such as supplier location.

In risk management an emergency team has to be prepared to deal with critical and catastrophic events. In huge areas such as industrial plants, refineries and urban centers one of the most difficult issues is defining where the emergency team will be based in order to minimize its dislocation to deal with catastrophic and critical events. A number of assumptions have to be taken into account, such as probability of the occurrence of the event and its criticality in terms of harm to employees, the population and the environment, etc. Identifying and quantifying the vulnerabilities of such complex systems is crucial for designing adequate protection, mitigation and emergency actions in the case of failure (E. Zio et al 2007).

The network methodology using the Center of Gravity and Hakini theory will be proposed to solve the emergency team location problem in the refinery taking into account risks, distances and other important related issues.

2 ANALYSIS METHODOLOGY

For this analysis a number of important steps have to be followed to achieve consistent results which can provide support for decision making concerning the position of the emergency team in the refinery.

According to the Center of Gravity Methodology the best location depends on the distance from one point to others and the importance index which is usually represented in terms of cost or profit. Therefore, the first step is to define the study boundaries as well as the point locations in specific areas. Moreover, its representation in terms of importance and the distance from one point to the others is essential. It is thus very important to know in advance in which area it will be possible to locate the emergency team.

After defining the importance index and the distance points the methodology will be applied to define the emergency team position. In addition, it is also necessary to check if in reality it is feasible to locate the emergency team at the indicated point. Otherwise, it

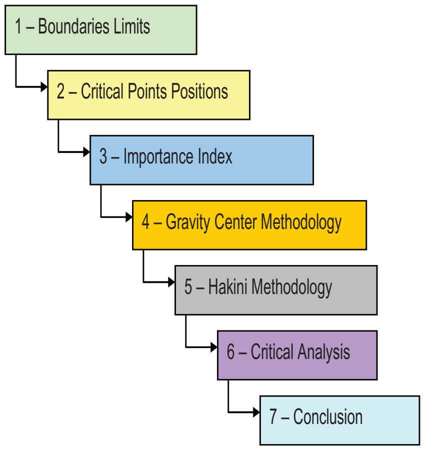

Figure 1. Network methodology.

will be necessary to look for the most feasible area near this point.

The second approach is Hakini Methodology, which is used to check the consistency of the first methodology. Since both methodologies are similar the same steps will be followed, but in the second methodology the best position of all boundary points is taken into account, because it is not feasible to locate the team within the area.

The final step is to analyze the position in terms of the feasibility of particular assumptions and limitations of real cases, such as impossible emergencies routes, traffic in the operational area and the flow of people and emergency resources. The methodological steps are shown in Figure 1 below.

3 NETWORK METHODOLOGIES

Network Methodologies are used nowadays in many logistic problems to solve the maximization or minimization of product throughput and transportation flows. It is a new approach to resolve this type of problem whose use has been intensified through software simulation evaluations in the last two decades. There are a group of network methodologies dedicated to finding the best locations in the network model. In this particular case study two of these approaches will be used. The first one is the Center of Gravity and the other one is Hakini Methodology. The basic concept is to discover the best location in a specific network in order to maximize flow or minimize time spent to provide service in the network. The difference between the two methodologies is that the first one takes any position in the network to be feasible for the best location. According to the Hakini Methodology, however, the best location will be one of the network points. In both cases sensitivity analyses will have to be carried out for the best location because in real life the network space has many limitations and assumptions that have to be taken into account.

These methodologies require a severity map of the area being studied (B. Mazzarotta et al 2006). Severity maps of the study area can be obtained through specific GIS (Geographic Information System) applications. In fact, a GIS permits the association of layers of information with specific locations (points, lines, polygons) identified on the basis of their geographical coordinates on a map. A number of GIS databases are available, including information such as land use, district boundaries, transportation networks, seismic areas, flooded areas, location of landslides, etc. In order to obtain risk maps the study area has to be selected beforehand.

3.1 *The center of gravity methodology*

In a network with many points on the regional plane, where n points are represented as (X_i, Y_i) and with the importance index $F_i, i = 1, 2, 3, \ldots, n$. The Center of Gravity is found by solving the equation below:

$$\text{MIN } Z = \sum_{i=1}^{n} F_i \cdot \sqrt{(G_x - X_i)^2 + (G_y - Y_i)^2}$$

The Gravity coordinate in Y will be solved by equation below

$$G_y = \frac{\sum_{i=1}^{n} \frac{F_i \cdot Y_i}{DE_i}}{\sum_{i=1}^{n} \frac{F_i}{DE_i}}$$

The Gravity coordinate in X will be solved by equation below

$$G_x = \frac{\sum_{i=1}^{n} \frac{F_i \cdot X_i}{DE_i}}{\sum_{i=1}^{n} \frac{F_i}{DE_i}}$$

And

$$DE_i = \sqrt{(G_x - X_i)^2 + (G_y - Y_i)^2}$$

To stop the interactions an error limit will have to be assumed, which will be represented as

$$\left|G_x^k - G_x^{k-1}\right| \leq \varepsilon \quad \text{And} \quad \left|G_y^k - G_y^{k-1}\right| \leq \varepsilon$$

This is the number of interactions necessary until the acceptable error is achieved. The first step will take into account:

$$DE^1 = DE^2 = DE^3 = DE^n = DE$$

Therefore, in the first step the equation coordinates will not take into account DE, so the equations will be as follows:

$$G_x^1 = \frac{\sum_1^n F_i \times X_i}{\sum_1^n F_i} \quad G_y^1 = \frac{\sum_1^n F_i \times Y_i}{\sum_1^n F_i}$$

The second interaction will use the results from the first interaction and will be the same until k interactions achieve the error limits. The general equation used from the second interaction onwards is shown below:

$$G_x^k = \frac{\sum_1^n \frac{F_i \times X_i}{DE_i^{k-1}}}{\sum_1^n \frac{F_i}{DE_i^{k-1}}} \quad \text{and} \quad G_y^k = \frac{\sum_1^n \frac{F_i \times Y_i}{DE_i^{k-1}}}{\sum_1^n \frac{F_i}{DE_i^{k-1}}}$$

3.2 *The Hakini methodology*

The Hakini Methodology looks at the network with a much lower number of points, taking an extreme point or vertex as the center point. This is a different approach and in some cases it is more realistic because it does not consider everywhere in the space in question to be suitable. The methodology follows three simple steps, namely:

In the first step the matrix with the shortest path between all the network points is created.

Next, each matrix element is multiplied by index points that represent importance in terms of cost, profit, risk and so on.

In the third and final step, all matrix elements in same line are added. The best point will be the line with the lowest value, which is represented on the vertex in the space in question.

These two methodologies above are able to define a single reference point in a group of points in space but they are not able to test whether response can be maximized over time. The importance index is determinant in most cases, but not in others, therefore the center point probably will change over time. To check this condition in order to locate the center point in the correct position over time it is necessary to know how importance varies over time, in other words, its lifetime behavior has to be simulated.

To solve this problem the probability density function (PDF) of the importance index over time has to be established to discover its frequency. Moreover, it is also necessary to simulate its behavior taken as a whole and considering all points at the same time.

Logistic problems usually have to define specific criteria before responding to a specific network point, which may be represented in the importance index. However, some cases, such as emergency situations, specific point requirements are not met, which can have catastrophic consequences. Therefore, is advisable in some cases to check response capacity in order to prepare a capacity that can meet one hundred percent of demands.

In this particular case, c it is not enough to change the center point based on its importance index frequency. It is also necessary to overload response capacity in order to meet demand. In this way the team which will fulfill the demand must be represented and simulation will be required to check the behavior of that team over time.

Direct Simulation will be proposed to check if team response capacity is sufficient over time.

4 THE DYNAMIC CENTER OF GRAVITY METHODOLOGY

One important limitation of the traditional Center of Gravity Methodology is that the importance index is constant over time. Consequently, the center point will be constant over time because both distance between points and its importance index are constant. In real life, despite the distance between points remaining constant, in most of cases the importance index does not. Even in relation to distance, in some networks new points are added in the network and some interference is required for the center point decision. Whenever this happens, it is advisable to carry out a new analysis in order to determine the new center point. When doing so the importance index changes, so a new analysis may be proposed, but it is not usual to consider its behavior over time. Therefore, in some cases the center point will not fit well with a specific period of time. To solve this problem it is necessary to establish the probability density function of the importance index and define a specific period of time to reanalyze the network. In fact, whenever an importance index changes a new analysis is required.

The figure below shows an importance index which represents accident frequency resources in an operational area.

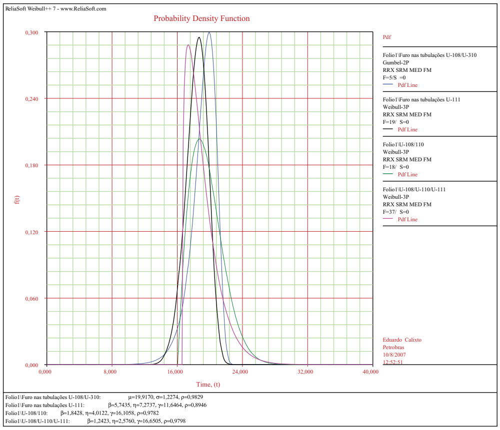

Figure 2. PDF corrosion.

The above figure represents PDF corrosion for different types of risk resources in a refinery. It means that corrosion is the basic cause of pipe linkage which in turn causes catastrophic accidents. Despite different PDF results, all resources have similar characteristics for this event. Therefore, the center point in this network will not change considerably because the importance index varies similarly over time.

If new events, such as critical and non-critical situations, are taken into account the importance index for pipe linkage will vary over time, forcing center point change over time.

Regarding its PDF behavior over time, a new interaction will be required in both network methodologies in order to analyze the index changes over time in center point decisions. It must be analyzed whenever the event frequency index will not be constant anymore.

5 RESPONSE CAPACITY SIMULATION

Network methodology usually considers that the response team will meet all requirements on time and that these requirements will occur one by one. However, this is not the truth and in some cases non-response to a requirement can have catastrophic consequences, such as in the case of accidents. To solve this problem response team behavior must be simulated over time. Simulation is a powerful tool to check emergency procedures which are expensive and difficult to check in reality (David & Isavit 2007). Direct simulation will be carried out to test response team performance. For this analysis block diagram methodology is used for PDF events and response team capacity. The main objective is to discover response team capacity in order to improve their capacity if necessary. In the simulation some results like reliability, availability, expected number of events and team capacity will be estimated. The results represent the probability of the events not happening in a specific time, the percentage of time that the events do not have an impact on the system, the expected number of events over time and response team capacity related to requirements. It is actually a good methodology for analyzing center point location over time, taking into account more than just distance and the static importance index.

6 CASE STUDY

In order to clarify the theoretical method a case study will be carried out. The case study stimulation is used to evaluate the methodologies in question and can also be used in other cases.

In the refinery area one of the most critical problems is the location of facilities, suppliers, warehouses and other types of logistics support for industrial plants due to the many limitations such as space, environment, risks to safety, and so forth.

The problem to be solved is at which point of space will the emergency team be located in order to respond to emergency requirements as fast as possible with lowest level of vulnerability. This means the best location may be near to an industrial plant but with a consequent high vulnerability. In order to solve those problems three models were proposed:

- ⇒ Center of Gravity Methodology;
- ⇒ Hakini Methodology;
- ⇒ Monte Carlo Methodology.

6.1 *Center of gravity methodology*

In the first case the network will be built up based on the positions of industrial plants in the area of the refinery, with each point representing a catastrophic risk resource. The importance index will be the probability of the catastrophic event happening. Therefore, the model will be located at the center point nearest to the most critical point, meeting the requirements of all points regarding distance and the importance index. The refinery area is show in Figure 3 below.

It is very important to state that the probability decision related to risk resource points was quantitative and the consequence risk analysis took into account catastrophic events as fire, explosion and toxic gas dispersion. The table below represents the fourteen points which represent the most critical events in the refinery area.

Using the equations given in section 3 and subsection 3.1 the result of the problem is the center

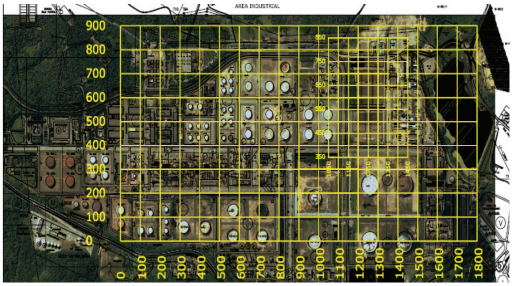

Figure 3. Brazilian refinery area.

Table 1. Center of gravity table.

	CG model		
Points	X	Y	F
U-1	1282,78	716,15	0,001024
U-3	1291,35	480,57	0,001286
U-4	1203,69	500,45	0,001548
U-5	1376,08	672,97	0,003317
U-2	1558,06	451,4	0,002447
Off site	497,697	939,599	0,013255
Gate 1	0	300	0
Substation	300	800	0,013255

Table 2. Center of gravity table.

Gravity center			
GX1	GY1	Erro X	Erro Y
815,7277	729,2447	0	0
GX2	GY2	Erro X	Erro Y
752,4623	585,2872	63,2654	143,9575

point which is found through the second interaction, as shown in Table 2 below.

The results of this methodology notwithstanding, it is necessary to analyze the feasibility of the location. Furthermore, in the case study two points are proposed for the location of the emergency team support, therefore sensitivity analysis is required.

The first proposed location is near the entrance gate of the refinery, represented by X(0,0) in the refinery map. The second is located around X(800,800) due to the available area. Based on the results of the model, the second one is the better position but there are two important events that undermine this solution. The first is that when it rains a lot the area becomes flooded, so in the case of emergencies it would be very difficult for an emergency team located in this area to respond to catastrophic accidents. The second is that the emergency route makes people go through the area from different points, which makes it difficult for the emergency team to move around freely. Using the Centre of Gravity methodology the circumferences around the center point define the nearest area to locate the emergency team. Therefore, the Hakini methodology will be analyzed in order to define the best point position and check the second and third best points.

6.2 *Hakini methodology*

As stated in sub-section 3.2, the methodology defines the best point based on distance and the importance index using a matrix and adds values to final index which take into account distance between points (meters) and the importance index (accident frequency). The Hakini results are shown in Table 3 below.

The best point is offsite because it contains the lowest value in the last right column in the matrix. The assumptions taken into account in the previous methodology in regard to flooding and the emergency route also applies. This assumption, the delay of team movement by more than 3 minutes, represents 1500 meters of movement, so this value will be added to substation and offsite to represent the delay. The new matrix with the new results is shown in Table 4 below. U-1,U-3,U-4 and U-5 are Unit plants around refinery area represented for point coordinates in map (figure 3).

In relation to these assumptions the substation and offsite is the worse location point for the emergency team. The U-613 location is better, but due to possibility of accident in the area, another point must be chosen. To locate the emergency team near the plant is to assume a high vulnerability because in the case of a catastrophic accident the emergency team will be unavailable. Therefore the best location is Gate 1.

Nevertheless, the two methodologies provide enough support to decide in which position the emergency team will be located. What is important is that in this position the emergency team will be available to deal with catastrophic events. The Monte Carlo methodology will be used to answer this question and will be looked at in the next item.

6.3 *Monte Carlo methodology*

The main objective of this methodology is to compare the impact of emergency localization in terms of response capacity. Its takes into account the probability of catastrophic events occurring over time and response duration time.

The first step is create the Safety Block Diagram in order to represent catastrophic events and simulate

Table 3. Hakini matrix results.

Hakini matriz 1									
Distance	U-1	U-3	U-4	U-5	U-2	Off-site	Gate 1	Substation	Total
U-1	0	0,3215	0,4644	0,3317	1,4682	7,953	0	11,9295	22,4683
Gate 1	1,6384	1,929	2,1672	5,6389	4,4046	13,255	0	10,604	39,6371
Substation	1,0752	1,6718	1,8576	3,6487	3,9152	2,651	0	0	14,8195
U-3	0,256	0	0,1548	0,6634	0,7341	18,557	0	17,2315	37,5968
U-4	0,3072	0,1286	0	0,9951	0,9788	14,5805	0	15,906	32,8962
U-5	0,1024	0,2572	0,4644	0	1,3459	14,5805	0	14,5805	31,33085
U-2	0,6144	0,3858	0,6192	1,82435	0	15,906	0	21,208	40,55775
Off-site	0,6144	1,8004	1,7028	3,6487	2,9364	0	0	2,651	13,3537

Table 4. New Hakini matrix results.

Hakini matriz 2									
Distance	U-1	U-3	U-4	U-5	U-2	Off-site	Gate 1	Substation	Total
U-1	0	0,3215	0,4644	0,3317	1,4682	7,953	0	11,9295	22,4683
Gate 1	1,6384	1,929	2,1672	5,6389	4,4046	13,255	0	10,604	39,6371
Substation	2,6112	3,6008	4,1796	7,2974	7,5857	22,5335	0	0	47,8082
U-3	0,256	0	0,1548	0,6634	0,7341	18,557	0	17,2315	37,5968
U-4	0,3072	0,1286	0	0,9951	0,9788	14,5805	0	15,906	32,8962
U-5	0,1024	0,2572	0,4644	0	1,3459	14,5805	0	14,5805	31,33085
U-2	0,6144	0,3858	0,6192	1,82435	0	15,906	0	21,208	40,55775
Off-site	2,1504	3,7294	4,0248	8,6242	6,6069	0	0	22,5335	47,6692

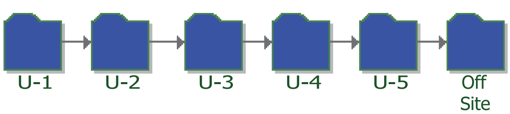

Figure 4. Safety block diagram.

them over time. Figure 4 below shows the Safety Block Diagram.

For the location of the emergency team at both proposed sites, namely the entrance gate X(0,0) and the substation X(800,800) there will be 100% availability and 75.6% reliability in twenty years. This means that 100% of time there will be no catastrophic accidents and there is a 75.6 % chance that none will happen over the next 20 years. The emergency team will have 100% of availability because they will not be required, as shown in Table 5 below.

The table above shows the emergency team availability (100%), the number of expected calls received and accepted and their average duration (one hour).

The scenarios can take place and require emergency support in many different events happening at almost the same time, in which case because the emergency team is occupied responding to one event it will not be available to respond to others. These scenarios must happen if critical and non-critical accidents are considered in the safety block diagram. In this case, in order to deal with the most critical events, a prior assumption would be proposed.

Table 5. Emergency team availability.

Detailed crew information	
Crew Policy: Portaria 1	
Call Summary	
Calls Received:	0,288
Accepted Calls:	0,288
Percent Accepted:	100,00%
Percent Rejected:	0,00%
Utilization	
Total Utilization:	0,2953
Average Call Duration:	1,0254
Total Wait Time:	0

7 CRITICAL ANALYSIS

The case study involves three types of different approaches used to define emergency team location and to discover whether this position has an influence on emergency team availability. Although catastrophic events occur rarely in reality, it has to be borne in mind that the event frequency was considered to be constant, which does not actually occur in real life.

For this reason, PDF events related to different risk resources were taken into account. As a result the dynamic network methodology was applied in order to verify center point modification over time, after which it was concluded that even PDF events did not have much influence on emergency team location, because most events occur around same time. Despite this, PDF events provide significant information allowing preventive action, such as pipeline maintenance to prevent corrosion which causes catastrophic events.

The other important point is that when a particular industrial point is taken into account it is necessary to consider all catastrophic risk resources in order to verify the results.

PDF events will be analyzed using Monte Carlo Methodology in order to check their influence on the final results.

8 SENSITIVITY ANALYSIS

In order to discover the influence on the final result a sensitivity analysis was carried out on the three methodologies in relation to PDF events. In the case of network methodologies, there were no modifications but there were in relation to the Monte Carlos methodology.

For the Monte Carlo methodology, in both cases of emergency team location, the Entrance Gate and the Substation, safety availability and safety reliability was 99.98% and 0% in twenty years. This means that 99.98% of the time there will be no catastrophic events but there is a 100% chance that they will occur during this period. Furthermore, looking at frequency index events in Figure 5 and comparing static and non-static frequency events, it is clear how important it is to take into account historical data. In the static frequency it is clear that the event is rare over fifty years but in the non-static frequency from fifteen years onwards the frequency starts to increase. This means that catastrophic events have a greater chance of occurring over time.

Despite the increase in the intensity of catastrophic events, as a result of which it is expected that there will be around thirty events in twenty years, the emergency team will have 100% acceptance of emergency call requirements in both location, namely the Substation and the Entrance Gate.

Even though they do not have an important effect on the resolution of problems, it is nonetheless very important to take historical data into account to establish the PDF in order to carry out preventive action whenever this is possible.

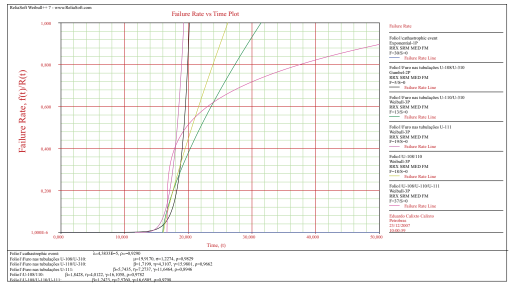

Figure 5. Safety block diagram.

9 CONCLUSION

The network methodology applied to the case study shows how important it is to consider other assumptions, such as PDF events and response capacity over time. In this specific case study they did not have much influence on the final result but it is nonetheless reasonable to take into account their occurrence depending on the different events considered.

The final decision was to locate the emergency team at the entrance gate because the events are rare over time and in both cases the response team capacity is 100%. Although the substation region is the best one according to the network methodology solution, the possibility of the area being flooded is critical and if this happens when a emergency team is required the consequences of not having the emergency team available are terrible.

The refinery case study must to be evaluated in relation to critical and non critical events and new plants to check the influences of these on the final results.

That methodology may be applied in offshore case study regarding one specific area with some platforms and drill in order to state the emergency team in the better position in order to attend catastrophic accidents. In Some cases, the offshore area change it's configuration in terms of facilities having ships frequently surrounded or gathering those platform Unit. Therefore, the dynamic approach is required.

REFERENCES

A.M. Cassula, "Evaluation of Distribution System Reliability Considering Generation and Transmission Impacts", Master's Dissertation, UNIFEI, Nov. 1998.

Boaventura, Paulo Oswaldo Netto, Grafos: Teoria, Modelos, Algorítimos. São Paulo, E. Blucher, 2003.

B. Mazzarotta & B. Silvetti, “A severity index to assess technological and natural risks in a study area”, Dipartimento di Ingegneria Chimica, Università di Roma “La Sapienza”, Rome, Italy. ESREL 2006.

E. Zio & G. Sansavini, “Service reliability analysis of a tramway network”. Department of Nuclear Engineering, Polytechnic of Milan, Milan, Italy, ESREL 2007.

IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems—IEEE Std. 493-1997.

Kececioglu, Dimitri, and Sun, Feng-Bin, *Environmental Stress Screening—Its Quantification, Optimization and Management*, Prentice Hall PTR, New Jersey, 1995.

Lafraia, João R. Barusso, Manual de Confiabilidade, Mantenabilidade e Disponibilidade, Qualimark, Rio de Janeiro, Petrobras, 2001.

Moraes, Giovanni de Araujo. Elementos do Sistema de Gestão de segurança meio ambiente e saúde ocupacional. Gerenciamento Verde Consultoria Rio de Janeiro: 2004

R. Billinton, and R.N. Allan, “Reliability Evaluation of Engineering Systems: Concepts and Techniques”, 1st Edition, Plenum Press, New York, 1983.

ReliaSoft Corporation, *Weibull++ 6.0 Software Package*, Tucson, AZ, www.Weibull.com.

V. Idasiak and David, “Accident simulation: Design and results”, Laboratory Vision et Robotique, ENSI de Bourges, ESREL 2007.

W.F. Schmitt, “Distribution System Reliability: Chronological and Analytical Methodologies”, Master’s Dissertation, UNIFEI, Oct./2002.