Risk Management in Urban Transport Systems for Logistics Planning in Brasília, Brazil

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Abstract
Considering ISO 31000 (2009)¹, the objective of this paper is to present how risk management in urban transport planning can ensure smaller uncertainties, raising sustainability, accessibility and reliability in urban logistics. While risk analysis is an important aspect in the management of critical structures, its use in urban planning is underrated, planners should use risk analysis as an urban logistics tool more frequently, their designs could consider damage-mitigating elements, risk monitoring and evaluation of multiple design options. These risk management technics are based on probabilities, expected consequences and risk limitation. An analysis of the method is made as the process is exemplified using the transport network of Brasília with its real characteristics and transport demand. The occurrence of floods is evaluated and probabilities are estimated using the concept of rainfall threshold. The results of studies regarding floods in the studied area are presented in a map and combined with the potential damage analysis to generate the risk study. The method proposes evaluation of risks in the transport network in order to estimate the most important infrastructures. Later, they are ranked from the strategic logistic point of view using risk as criteria. Consequently, the most recommended improvements are identified and general suggestions for urban design are given that can lead to further developments in the transports and urban logistics planning. The process is expected to contribute with future studies on infrastructure planning and raising awareness on risk management in growing cities logistics.

Keywords: Risk management, urban logistics, transport planning.

Introduction
Brazil is known as a Country with continental dimensions, lots of developing cities, growing economy and consequently a consumer and producer market whose commercial activity and necessities are expected to expand in the future. Even though there is no consensus about how big will be the Latin American cities growth rate in the near future, there is no doubt that there is a need to enhance capacity and reliability in urban transport infrastructures, many times considered inappropriate even for today needs.

The international context of urbanization and gigantic demand for better urban infrastructures to allow the transport of food, people, goods and materials for industrial activity are big challenges for developing countries. The expansion of the consumer market is noticeable, helped by the rise of the purchasing power and overall market demand for different goods, of bigger industrial complexity. The tendency of bigger expectations when it comes to urban mobility, pushed by the daily problems experienced by the population of a developing economy and new technologies make this context an important opportunity for the development of new strategies aiming at more efficient cities. Not only to ensure that the supply needs are fulfilled, but also to guarantee better services for the urban population, it is fundamental that there is an adequate transport infrastructure network with reliable links and capable of transporting all the users and the goods required. Many Brazilian cities, especially the newer planned ones have organized central infrastructures surrounded by suburbs, sometimes unplanned, inadequate and more distant, therefore more exposed to damaging occurrences, such as floods or landslides.
This is the main motivation to perform deeper analysis, planning and control of the urban infrastructures in Brazil, including the complex urban transport network, especially its most critical elements.

Because of this atmosphere, urban management when it comes to transports in Brazil is usually surrounded with an urgency context, what generates a situation that in some cases can contribute to the lack of quality control in design, new infrastructure construction and operation. The situation today, when it comes to Brazilian urban transports, indicates that the demand for new infrastructures and better control and will be intensified with the new governmental perspective for the area, which is based on trying to encourage public transport.

Even though there is this urgent situation in upgrading and remodelling Brazilian urban infrastructures, it is always necessary to keep in mind that any improvements or any kind of investment in infrastructures must be made according to rational methods, following the knowledge of engineering and architecture and being guided by the principles of efficiency, safety, reliability and financial sustainability.

Background and objectives
The studies concerning risk and management are being more and more considered in the Federal Government decisions, especially because of the recurrence of great landslides in Brazilian cities in the last years. Lately, initiatives directly linked to disaster prevention and mitigation took place in Brazil. Good examples are the creation of the National Center for Monitoring and Alert of Natural Disasters - Centro Nacional de Monitoramento e Alertas de Desastres Naturais - Cemaden/MCTI, in 2011, and bigger public investments in civil safety government departments, drainage works and earth retaining walls, included in the Growth Acceleration Program – Programa de Aceleração do Crescimento – PAC.

Furthermore, focusing in occurrences that have direct impact on transport strategic infrastructures, the government is getting more concerned with urban mobility and logistical costs in cargo transport, so that it doesn’t harm the quality of life or supply of goods in urban areas. Interruptions in transports may cause huge proportion damages, creating contractual losses and other effects with direct impact on the economic growth of the Country and in people’s well-being.

Urban transport infrastructures are totally related to this scenario, because they are located in densely inhabited areas, places where it is common the occurrence of potentially destructive phenomena of different kinds, such as floods, landslides, protests or even terrorism. In important infrastructures such
occurrences may cause enormous economic losses, environmental impacts or human fatalities. Many times it is perceived insufficient planning or lack of urban investigation that could help design solutions, risks are many times not considered with the needed approach. Therefore, an important tool many times not used as it should is the risk management process, useful for decision making and prevention and mitigation of urban occurrences.

Authorities and companies use to say many times that landslides and floods are related to unpredictable natural situations. Intense rain and geological or geotechnical factors not identified or predicted are usually blamed for slides and other similar phenomena. However, it can be said that it is common to find design or operation failures in the management of many critical infrastructures, they can be originated in the stages of geological, topographical or hydrological investigation, or in identification of important conditionings. In other words, many times, the evaluation of the variability of parameters is not considered, ignoring the random nature and probability of occurrence of natural triggered phenomena such as the ones related to soils or water.

This study believes that the use of risk management, including the estimation of probabilities, possible consequences and acceptable risk limits constitutes a relevant tool to support the design creation process in urban environment in general, including transport infrastructures. Furthermore, in can be said that designers that care about risks in the right time are capable of identifying menaces and including in their studies natural disaster mitigating structures still in the first stages of designing, ensuring smaller uncertainties and bigger reliability and efficiency in the built elements.

Therefore, the objective is to apply a risk management process based on the one proposed by ISO 31000 (2009)¹, Risk Management – Principles and Guidelines, with an organized and clear method, to perform an analysis of a real study case: evaluate the flood occurrences with relevant consequences in a Brazilian city. The risk management process, according to ISO 31000 (2009)¹ is presented in figure 2. This procedure, widely used internationally to risk zoning is structured and well defined in the literature. Its purpose is to help decision making between alternatives to remediate damage, determine areas of high risk or propose interventions to keep the risks of an enterprise within acceptable limits.

![Figure 2: Process of risk management according to ISO 31000 (2009), Risk Management – Principles and Guidelines.](image-url)

Concepts
First of all, it is essential to define clearly the meaning of the concept of risk management process and other related vocabulary. Risk, according to ISO 31000 (2009), is understood as the effect of uncertainties for the accomplishment of objectives, so, it is the intensity of the deviation of the custom service condition caused by a situation that acts as predicted by probabilistic laws. It should be interpreted as an indicator of the combination of the probability of a specific situation happening and the intensity of its potential effects on a structure, surroundings or even the society affected.

The risk associated with fatalities in natural disasters, for example, should consider for a certain place and time the kinds of possible occurrences and the number of deaths expected, based on historical data of other similar accidents, for example. Differently, if the study aims at estimating risks related to structures, properties or goods, usually it should first predict the probability that damage is caused to the element, then, the estimated cost or damage in case the intervention is actually needed must be calculated.

In its most simple form, the quantitative risk is defined commonly in different fields of human knowledge based on the multiplication of these two factors: the probability that a negative effect happens and if so, the expected intensity of its consequences. So, the risk may be said as linearly dependent proportionally to the changes in probabilities of existence of an occurrence and its resulting damage. Mathematically it can be written as:

\[ R = P(M) \times C \]

R is the risk associated to a menace and to a studied predefined system, \( P(M) \) is the probability of occurrence of a menace, a harmful phenomenon of determined intensity and characteristics and \( C \) is the consequence when the system is affected by the menace.

Both the forecasts of consequences and probabilities are seen as challenges to the manager of infrastructures because of its great complexity. The process of predicting consequences should consider direct and indirect damages, whose costs are hardly measurable. The complexity of obtaining an occurrence probability is given by the great number of parameters that can influence the deflagration of a phenomenon through time and its variabilities. It is important to note that this is a process often discussed in conjunction with another concept often interpreted as its objective, the reliability.

Achieving high reliability implies lower likelihood of service interruptions and making the potential damage controllable and more easily retrievable, thus it is related with the principles of risk management. There is a wide range of relevant concepts commonly used related to the maintenance of satisfactory conditions of service, whose definition should be explained here, at least superficially.

As the concepts will apply to infrastructure of great importance, it is considered useful to define a critical element: it is a relevant entity which provides tradable goods or services that are so vital in usefulness or importance that their incapacitation or disruption would have a measurable debilitating effect on society in its various spheres, state, region or country, according to Gheorghe (2004).

Establishing the context and Identifying Menaces
A lot of factors can interfere with the probability of occurrences and the potential damage, some are characteristic of the surroundings, some are dependent on human action, and even though they are hardly fully identified, classified and used in a model study, the best the characterizations of the occurrences is, the better the results are. The need of a careful and detailed implementation of the context definition stage should be highlighted.

The search for data about the network studied was performed, aiming at gathering information about the transport system, most important infrastructures and user needs. The Federal District of Brazil is divided in regions each with its own administration, but all under the responsibility of the governor. Brasilia, the main city and capital of the Country is a planned city, founded in 1960, but already with a big population and suffering from common urban problems.

Specifically, it must be said that Brasilia, the central area of the Federal District, surrounded by the lake Paranoá, offers approximately 80% of the job opportunities, but most of the population, around 83%, live in more distant administrative regions (Pricinote, 2008), especially to the south.

The definition of the study context must be followed, naturally, by the further identification of possible threats that could cause occurrences. In this text are studied flood occurrences in the Federal District of Brazil. Geological or hydrological constraints are often responsible for damaging phenomena and many methods can be used to estimate the probabilities of occurrences. So, it is essential to investigate the characteristics of the phenomenon in the specific location, so that its understanding is as complete as possible.
In the region around Brasília, the terrain is generally regular and flat, floods are spread and usually not as intense as in other cities in Brazil, especially because of the open uninhabited space surrounding the urban area that help rainfall water to drain. Most of the times these occurrences are linked to inefficient road or urban design, therefore, the method used for predicting the probability is by searching for historical data.

Having specified the occurrence, the infrastructures under analysis had to be chosen. The complete network was simplified to a more representative network containing the most important traffic axis in the urban area. The criteria used to select the links for analysis was based on the concept of critical infrastructure. The study was performed on the elements considered most relevant to the usual city traffic in order to rank the ones that have the highest risks and therefore should have priority in city management.

![Figure 3: Chosen elements for risk analysis and management.](image)

It is important to say that the management process should be studied for a given infrastructure exposed to a certain phenomenon, it is suggested that further studies are done with due consideration of the specificities if one wishes to study another mechanism that generates damage, for example.

**Mathematical Modelling and Risk analysis**

The risk analysis contains the calculations effectively directed to determining the potential effects from occurrences on services, associated with the probabilities of menacing phenomena. Both are addressed at this stage: the steps of determining the probability of occurrence and the estimation of expected consequences. The strategy of simplifying the complexity of risk analysis through its division into studies of potential damage and probability of occurrence is often found in the literature. Damages caused in each scenario of occurrence are calculated with models, statistically or through historical information and then are multiplied by the associated probabilities.

The classification of a phenomenon as destructive can be made by setting a criterion, for example, the estimation of the damage caused to the users could be compared with a threshold. It is possible to convert the historical data into a probability, considering the years of analysis, the rainfall that triggered the occurrences and the number of phenomena registered. This last method is the one to be used in this text.

The probability that a rainfall could trigger a flood can be estimated using local rainfall database over time combined with the study of rainfall threshold. According to Jaiswal and van Westen (2009)\(^4\) the rainfall threshold is a concept linked to the intensity or minimum rain duration necessary to trigger menacing phenomena related to rain, such as landslides. The same analysis used by those authors could be useful for floods analysis, therefore, based in this method, a study was made by Batista (2014)\(^5\) regarding news of floods published by local newspapers. His study searched for information on previous cases of floods in the urban area of the Federal District for 14 years, later locating them on maps. Batista (2014) associated the news related to relevant floods to the database available from rain gauges in the hours before the occurrence and then calculated the probability that each rain intensity could cause floods in the area closer to the rain gauge.

According to Batista (2014), the probability that a flood happens considering that the rainfall threshold is exceeded is mathematically expressed by:
\[ P[L/C > C_t] = \frac{L}{\lambda} \quad \text{(eq.1)} \]

\( L \) represents the number of flood occurrences in a given time and \( \lambda \) is the number of times that the rainfall threshold was reached in the same period. According to Jaiswal and van Westen (2009), the annual probability that a specific rain intensity is exceeded can be determined using Poisson coefficient, so the authors suggest that the following equation can be used to estimate the probability that the rainfall threshold in exceeded:

\[ P[C > C_t] = P[\mu(t_i) > 1] = 1 - \exp\left(\frac{-t_i}{\mu}\right) \quad \text{(eq.2)} \]

The authors define \( \mu \) as the coefficient between the number of times the rainfall exceeded the rainfall threshold (\( \lambda \)) and the total duration of the study, in this case 14 years. \( \eta \) is the total number of flood occurrences and \( t_i \) is the time associated with the probability, in this study 1 year.

Batista (2014) suggests that it is possible that a specific amount of rainfall that previously triggered a flood is once again reached or even exceeded without causing new menacing phenomena. So, it is important to consider the intersection of both events. In other words, the most relevant probability is the probability that the rainfall threshold is exceeded (eq 2) combined with the probability that a flood occurs given that the rainfall threshold was exceeded (eq 1). This concept can be expressed mathematically according to the following equations:

\[ A = P[C > C_t] \cap L \]

\[ A = P[C > C_t] \cdot P[L/C > C_t] \quad \text{(eq.4)} \]

Using these equations, Batista (2014) managed to study 26 rain gauge combined with the flood database. A graph relating the flood probability to different predefined rainfall thresholds is presented ahead as an example.

![Figure 4: Probability associated to the equations (1), (2) and (4) in the administrative region of Taguatinga. Batista (2014) modified.](image)

It can be seen that the intersection of both events happens more frequently at a rainfall threshold of 70mm daily, when there is a higher probability of floods occurring given that the rain threshold was exceeded (eq 4). Analyzing all the 26 rain gauges with the same procedure, considering their locations and using the Inverse Distance Weighted method resulted in the following map that indicates approximately the probabilities of floods in the Federal District.
The consequences study is based on the Origin Destination Matrix, provided by local authorities transport usage surveys. Using the data available and network analysis it is possible to estimate the total distance of all the travels made by users of the transport system from one point to another in the city area within the period of a day. This distance indicates how efficient is the transport system and how far are the destinies from the origins of local transport needs. Since the distances between origins and destinies do not change, by performing the total distance analysis on the usual network and on the network after the interruption of some elements a comparison of efficiency of the transport can be made. The comparison indicates the intensity of the damage to the transport system caused by the flooding occurrence because the total distance will be increased proportionally to the use of less efficient routes. Therefore, using network analysis based on the total distance, the calculation of the estimated consequences of an occurrence is made possible and can be applied to risk analysis. The selected transport network elements previously discussed were studied using this method. The increase in the total distances of all the routes is calculated by subtracting the total distances considering the entire network from the total distances considering that a given element is interrupted by a flood. The increase in the total distances of travels resulting from the interruption of each element is presented in the table below associated with the probability of a flood occurrence in the same element.

Table 1: increase in the total distances of travels associated with the probability of a flood.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Consequence - increase of distance (Km)</th>
<th>Probability of damage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPIA SUL</td>
<td>2,277,105.2</td>
<td>10.92</td>
</tr>
<tr>
<td>EPIA NORTE</td>
<td>14,066,160.6</td>
<td>28.06</td>
</tr>
<tr>
<td>EPIA CENTRAL</td>
<td>638,200.7</td>
<td>4.37</td>
</tr>
<tr>
<td>PONTE JK</td>
<td>2,738,901.2</td>
<td>1.76</td>
</tr>
<tr>
<td>EPCL</td>
<td>3,821,276.9</td>
<td>20.89</td>
</tr>
<tr>
<td>HELIO PRATES</td>
<td>199,050.9</td>
<td>17.11</td>
</tr>
</tbody>
</table>
Risk Evaluation and Discussion

Risk analysis studies containing the probabilities and consequences don't have great applicability in itself if they are not inserted in a context that can provide conclusive information on the safety and reliability of infrastructures. The usefulness of calculating flood risks in cities has two purposes: as a tool for conducting evaluation studies and risk management strategies and as an aid to decision taking.

The infrastructure elements that represent EPCL and EPIA NORTE can be used as examples of the comparison made in the risk evaluation step. At EPCL the total distance increase was estimated as approximately 3,821,276.90 Km, while at EPIA NORTE the total distance of the travels increase in case of an interruption was 14,066,160.50 Km. From the probability analysis it can be said that the occurrence of a flood in EPCL is around 20.89% annually, and the probability of a flood in EPIA NORTE is 28.06%. The risk indicator calculated for EPCL is equivalent to 798,264.74 km while the risk in EPIA is approximately 3,946,964.66 km. So EPIA NORTE should be a priority from the point of view of urban logistics when compared to EPCL.

By multiplying the expected consequences of an occurrence to the users by the probability of floods happening, the following risks in kilometers were calculated.

<table>
<thead>
<tr>
<th>Table 2: Risk indicator calculated for elements</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Elements</td>
<td>Risk indicator (Km , %)</td>
</tr>
<tr>
<td>EPIA SUL</td>
<td>248,659.89</td>
</tr>
<tr>
<td>EPIA NORTE</td>
<td>3,946,964.66</td>
</tr>
<tr>
<td>EPIA CENTRAL</td>
<td>278,89.37</td>
</tr>
<tr>
<td>PONTE JK</td>
<td>48,204.66</td>
</tr>
<tr>
<td>EPCL</td>
<td>798,264.74</td>
</tr>
<tr>
<td>HELIO PRATES</td>
<td>34,057.61</td>
</tr>
</tbody>
</table>

It is important to notice that distances can be converted into money, the usual unit for risk studies, using simple conversions such as the average fuel consumption of vehicles and the cost of fuels. Risk can even be converted into approximate time spent during logistics operations if the average vehicle speed is considered.

Even though the value of calculated risk has no direct meaning because it is obtained by the multiplication of a percentage by a distance, it is a very relevant indicator of the intensity of potential damage and probability of a given menace. In engineering, it is common to face the tradeoff between cost and safety. In theory, it is possible to guarantee almost zero probability of harmful occurrences if there are enough resources spent in this way. However, it can't be forgotten that engineering must be concerned with the principle of economic feasibility, and so, the money used to maximize the safety coefficient should be proportional with the importance of an element.

The risk evaluation can be used to identify situations when it is necessary and feasible geotechnical, hydrologic or other similar engineering intervention. A challenge for a future study is to determine a method to estimate an acceptable risk limit, in this study the risk values should only be compared with each other. The elements whose risks are higher should be made priorities to ensure a more reliable urban logistic infrastructure, requiring in this case special operation plans or construction of preventive structures, avoiding interruptions or restrictions to roads and streets.

The private transport is widely known as the main urban transport option in Brazil, even with great potential to use other kinds of transport. The historical, economic and political reasons for this preference are visible, but usually ignored. Even though it is commonly said that bicycles and public transport are more adequate ways of transporting Brazilian population in most of the cases, especially when it comes to the biggest cities, the management decisions usually don't consider these options. However, a natural process of change in public opinion and in the government is taking place, slowly but constantly, to modify this transport context so that it turns out to be more diverse, sustainable and consequently more resistant to damaging occurrences such as floods in the future.
Risk Treatment and Conclusions
There is a last step in risk management before reinitiating the risk management again, since it is a continuous process, as the method indicates. This stage is the treatment and intervention in risk and it consists in using strategies or constructing engineering works to reduce the probability of occurrence, for example, new drainage solutions. Other options are the elaboration of a contingency plan in case of accidents, whose primary goal is to reduce consequences such as traffic jams or propagation of cascading negative effects.

Based on the definitions presented before, by multiplying the probability by the potential damage, it is possible to find the element with the highest risk. In this case, the value of the risk to users of the urban transport system is the highest in the element EPIA NORTE, where the risk calculated is approximately of 3,946,964.66 as a result of the combination of the importance of this infrastructure element to the urban transport network with high probability of floods. For the risk treatment, any engineering interventions that could turn the existing probability into a more reliable situation, with probability of occurrence below the one calculated would be useful for the population from the point of view of the urban logistics.

When it comes to improvement suggestions, the creation of new elements in the transport network parallel to the ones identified as the most critical, specially EPIA NORTE, could lower considerably the consequences of floods, since there is more drainage area available, reducing occurrence probability, but on the other hand it increases distances and reduces transport options in case of interruptions in infrastructures. This is an important factor that influences directly the city transport risks. The traffic jams in Brazilian Federal District occur exactly in the infrastructures where there are the biggest convergences of traffic coming from other regions to Brasilia in the morning and in the other direction in the end of the day as seen in the risk analysis presented. The lower income received by the families that live in the most distant suburbs aggravates this situation of spatial exclusion and limits the opportunities of job, education, health, leisure and other services to the more isolated poorer population.

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References