

## **Automated Risk Assessment in Construction: Combining Novel Concepts with Cutting Edge Technologies**

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### **Abstract**

Although, an issue that applies to all aspects of a construction project, risk has always been primarily related to workers safety. The risk of accidents requires appropriate identification, assessment and response in all phases of a construction project's life cycle. This, in turn, is achievable by applying a systematic approach that can effectively measure the right indicators of an emerging risk. In this paper, the novel concept of “risk component” is defined and shortly described through different examples that correspond to different risks. From another starting point Automated Data Collection (ADC) technologies are briefly reviewed, in order to investigate their appropriateness for measuring risks components. A comparative presentation of the main ADC technologies highlights their advantages and disadvantages and indicates the most effective among them in assessing risk through risks components measurements. Through this presentation, it is concluded that vision-based tracking methods are the most effective in quantifying risk components. This result is validated with a case study that simulates the operation of a proposed simple system for construction site monitoring by the use of vision-based tracking methods. The application example clearly demonstrates the effective combination of theoretical and technology innovation in construction risk assessment.

### **Keywords**

Risk Analysis, Construction, Monitoring System, Automated Data Collection, Vision-based Tracking Methods

### **1. Introduction**

Construction is among the most risk-intense industries. This is due to several reasons including: a) the demanding requirements of modern, complex technical projects coupled with the improper training of workers, b) the low level of automation in the construction process, c) the dynamic environment of work that, often, requires the execution of dangerous tasks and d) the inappropriate implementation of health and safety measures, either due to incomplete design or due to negligence and non-compliance of workers with them. While, these risks, i.e. the risks related to health and safety in the construction site is the predominant type of risks when talking for the construction industry, other types of risks such as legal, financial or managerial risks are also of great importance, since the response to them has a direct impact to any construction project's success (Xenidis, 2006). Therefore construction risk management is a highly demanding endeavor that requires proper training and the use of the appropriate tools and techniques.

Among the most important requirements for a successful implementation of risk management is the understanding of the risk from the risk analyst (Fung *et al.*, 2009). Unless the risk analyst has a clear idea of what are the sources and the constituents of a potential risk any approaches and measurements used are susceptible to false assumptions and subjective judgments and expectations, which lead to ineffective risk

response decisions and eventually to losses and damages upon risk occurrence. While understanding the nature of the risk is of utmost importance, the ability of a dynamic monitoring of the construction process, in order to decide, based on the most updated data, for the project's risk response capacity is also of huge significance. This is due to the fact that conditions in a construction project change often suddenly and drastically. Therefore, timely identification and continuous monitoring and measurement of the proper risk constituents are essential for effective risk management in construction.

This paper discusses the concept of "risk component" that introduces a new approach in risk understanding and quantification aiming at a more practical and more realistic way to identify and estimate risks. Furthermore, it investigates, in brief, current technologies of Automated Data Collection (ADC) and suggests a comprehensive methodology of assessing risks in construction sites through the integration of the novel theoretical concept and the modern ADC technologies. The paper concludes with a realistic simulation example of the application of this methodology that demonstrates the potential advantages and benefits of the new approach.

## 2. Risk Assessment Through the Measurement of Risk Components

The concept of risk, although extensively described and analyzed in the literature, still lacks a single and generally accepted definition of its content. This is mainly, because it is strongly dependent on the different background of each individual risk analyst in terms of experiences, behaviors and attitudes against risk. Therefore, the same risk situation may be interpreted in a different way by different risk analysts, because of the various conceptions of the content of risk (Baloi and Price, 2003).

The two dominant approaches in risk interpretation are those of considering risks either in terms of the probability of occurrence of a hazardous event (Jannadi and Almishari, 2003) or in terms of damage anticipated upon the occurrence of a hazardous event (Gao and Handley-Schachler, 2004). Both approaches have certain limitations that prevent from a robust framework for risk interpretation and these limitations are another reason for the relational conception of risk in practice.

Xenidis (2006) has proposed a generally applicable definition of risk that allows for a different approach in understanding the concept. According to him: "*The risk of an activity or event is a future contingency that is described from constituent elements and has a negative result upon occurrence*". The term of constituent elements is further defined as: "*Certain features which are inherent to the occurrence of a given risk and identifiable to various levels upon risk occurrence*".

Based on the above, risk is defined as a set of  $RC_k$  components (i.e. the constituent elements), which are measurable and identifiable upon risk occurrence. Risks components can be identified independently from specific risks and constitute the field  $Z$  of risk components as expressed in Equation 1.

$$Z | \{RC_k\}, k = 1, \dots, n \text{ (n a real number)} \quad (\text{Eq.1})$$

$Z$  includes all risks components that can be combined in between in different ways and result to different risks. Therefore, each subset of  $Z$  (i.e. each group of different risks components) represents a different risk. Based on this approach, the crucial point is the identification of the various risks components, in order to identify the upcoming risks. A simplistic example may be drawn from the situation presented in Figure 1.

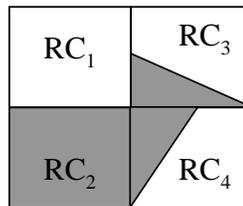
Figure 1 represents two laborers working on a scaffold. The obvious risk is that of an accident of falling from the scaffold ( $R_{fs}$ ), while another, less obvious, yet critical risk, is that of an accident of injury due to the fall of an object from the scaffold ( $R_{fo}$ ).  $R_{fs}$  and  $R_{fo}$  are two discrete risks with common and unique risks components in between, which are indicated with arrows in the figure. The common components are the scaffold (green arrow), the workers (red arrows), and the tools (blue arrows) used by the laborers,

while the unique components are the tools which are not used by the laborers (yellow arrows) and the safety measures against fall of a person (e.g. safety ropes) or an object (e.g. safety net). The latter are not indicated in the figure, because they are not visible there.



**Figure 1: An Example of Identifying Risks Components in Construction**

The occurrence of  $R_{fs}$  or  $R_{fo}$  depends on the existence of the specific risk components identified in Figure 1. Furthermore, the severity of both risks depends on certain properties of the components. For example the scaffold is more dangerous if the planks are not properly placed and hinged; the tub is more dangerous if it is full instead of being empty, etc. Therefore, for each risk component a range of values may be defined to represent the different levels of presence (degrees of significance) of the component. Figure 2 graphically represents the concept of risk occurrence in the proposed theoretical framework.



**Figure 2: A Graphical Representation of the Risks Components of a Risk**

In Figure 2, an assumed risk comprises four risk components. The shaded area for each component denotes the respective level of presence, while the total shaded area is the degree of occurrence of the risk. As the level of presence increases for a component, the severity of the risk is considered to increase respectively. From the figure, it is obvious that the shaded area for each component may vary from 0% (e.g.  $RC_1$ ) to 100% (e.g.  $RC_2$ ) of the total area associated with the component.

Figure 2 implies that all risk components are, in principle, equally possible to exist upon the occurrence of the risk (i.e. all elements are associated with equal areas). Although practically some risk components may appear to a greater degree than others, this is due to the specific conditions of the case under study; in theory all risk components are equal elements of the field  $Z$  and, therefore, of equal level of presence upon risk occurrence.

The identification of the risks components, the determination of the various levels of presence of each one of them, and the integration of all risk components to a single value that represents the overall risk are tasks that can be achieved through the use of appropriate tracking and measurement tools and methodologies. ADC technologies can be applied for the direct, fast and dynamic quantification of risks. Section 3 explores this possibility by examining and comparing the prevailing ADC technologies in construction.

### **3. Risk Estimation with the Use of Automated Data Collection Technologies**

The construction industry is gradually recognizing the necessity of timely collection of any kind of useful data and information for the construction process (Rebolj *et al.*, 2008). In this view, it increasingly introduces the use of new tools that are capable of continuously transferring data in real time for construction site activities, materials and equipment. These tools and technologies are currently used, mostly, for material and equipment management, scheduling and construction site management by providing data and information for stocks, readiness and place of equipment and specific site conditions that require the construction manager's attention (Tamvakis, 2010). The collected data and information are analyzed and the respective decisions are taken. However, this far, ADC technologies are not yet exploited in the field of risk management, despite their appropriateness and need for such a use (Aven and Kristensen, 2004; Flage and Aven, 2009). Especially in the context discussed in the previous section, ADC technologies are definitely very useful because they can provide, in real time, an identification and measurement of each of the components of the risk under investigation, resulting in this way, to the timely estimation of the risk occurrence level. The quantification of risk can be fully automated with the use of the appropriate software that shall collect the data from the field and calculate the values of the risk components and the overall risk as well. The automation of the risk assessment process apart from the fast provision of the required data ensures their accuracy, thus allowing for effective decisions on the implementation of risk response measures.

There are several ADC technologies with different features that render them more or less effective for the measurement of the risk components as described in the previous section. Among them, Bar Codes and RFID are mostly applied in construction sites, while Vision-based Tracking Methods are, increasingly, gaining interest in the construction industry (Brilakis *et al.*, 2006). The main features of these technologies are briefly presented in the following subsections along with a comparative presentation that highlights their pros and cons and indicates the most effective ADC technology for application in the risk assessment process.

#### **3.1 Bar Codes**

Bar codes are a well-known technology of automated collection of data, which are included most often in a label that bears a bar code. These data are static, i.e. they cannot be modified once they are included in the bar code. Bar codes can identify the element on which they are attached but not its quantity. It is a rather inexpensive technology that significantly reduces errors in data collection, assists the increase of productivity and contributes to the effective exploitation of resources (Nasir, 2008).

#### **3.2 Radio Frequency Identification**

Radio Frequency Identification (RFID) is a general term that is used for the automated tracking and identification of objects or material with the use of radio waves. The most common RFID method involves the recording of the identification data to an electronic tag that is attached to the object; this tag can exchange signals with an RFID reader (interrogator) that transforms receiving radio wave signals to digital data, which constitute the input to a mainframe that stores and processes them (Nasir, 2008).

The RFID technology can provide in real time the exact position of an object or material provided that the reader is passed close enough to the tag and without obstacles that prevent or divert the transmission of the radio waves.

#### **3.3 Vision – based Tracking Methods**

Vision-based tracking methods are based on the use of video cameras that collect images, which are processed with the use of appropriate algorithms and provide accurate results on material and equipment

tracking. A properly designed network of cameras can be a cost-effective approach for the monitoring of many elements at the same time; furthermore, it can effectively cope with the problem of frequent changes of conditions on site or the requirement of coverage of wide areas in large construction sites (Teizer and Vela, 2009).

### 3.4 Comparative Presentation of ADC Methods

Table 1 compares the methods presented in subsections 3.1 – 3.3 on the basis of specific characteristics that affect their applicability and effectiveness in construction sites.

**Table 1: Comparison of characteristics between Bar Codes – RFID – Visio-based Tracking Methods**

Characteristics	Bar Codes	RFID	Visio-based Tracking Methods
Visual contact between the element and the device for data collection	Required	Not required	Required
Reading spectrum	≈ 1in.	1in. ÷ 100ft	>> 100ft
Input data renewal	Static. Data included in bar codes are not modifiable	Dynamic. Data can be updated in the “read-write” type of labels	Dynamic. No labels required.
Input data volume	Few data can be included in bar codes	More data can be included in labels compared to bar codes	All existing data are included in images
Tracking ability	Identification of an element but not of its quantity	Identification of both an element and its quantity	Identification of an element and, conditionally, of its quantity
Concurrent data collection	No. Bar codes are read one at a time	Yes. Multiple labels are simultaneously readable	Yes. All data available in the visual spectrum are simultaneously readable
Reading rate	Slow. The scanner reads one by one the bar codes	Fast. 1000 labels per second can be read.	Dependent on the analyst’s requirements.
Durability in the construction site	Not much	Yes provided that the label is properly encased	Satisfying
Cost	Very low cost	High cost	Low cost

Table 1 presents the limitations and strengths of the ADC technologies, which are mainly used in construction sites. Considering the requirements for an effective assessment of risks in the new framework that was discussed in section 2, vision-based tracking methods constitute the most effective technology because they can quickly: a) identify risks components, b) measure, concurrently, the various properties of the different risk components, c) assess an overall risk by summing up the risk levels of the risk components, and d) monitor the risk components in a dynamic way.

Section 4 presents an application example of risk assessment with the use of a simple “two-camera” network. The example demonstrates the applicability of the proposed theoretical approach for assessing

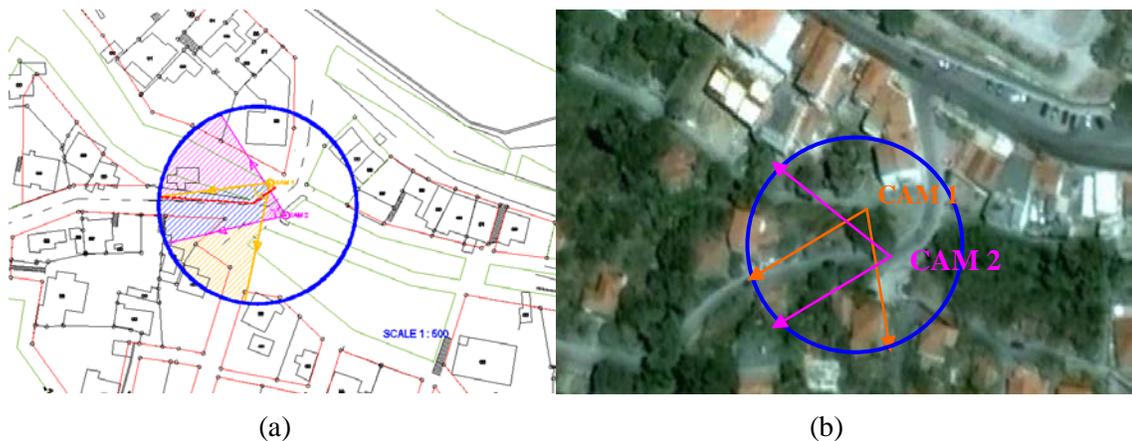
risks and the compliance of this approach with cutting edge technology used for construction site management.

#### 4. An Example of Assessing Risk Components with the Use of Vision-based Tracking Methods

To provide a proof of concept for the proposed approach in estimating risks, an example of application is presented. This method is similar to the one presented by Giretti *et al.*, (2009) in a similar representation of a system for automatic real-time health and safety management on construction sites.

In the example, the construction work is the replacement of a part of the sewage pipeline network for a length of 600m. The work includes the pipeline excavation at a depth of 2 meters along a minor urban road, the placement of the new pipe and the reconstruction of the road. In order to avoid disturbance in the district and to prevent from accidents, the work is performed in parts, i.e. every 10 meters.

The monitoring system of the construction works area consists of two solar powered cameras, which are placed on 5 meter - tall metal poles and a mainframe that receives wirelessly the videos from the cameras and with the use of the appropriate software processes the images to extract the required output for the assessment of risks. The minimum number of required cameras is two and they must be placed in such a way so as to ensure the maximum coverage of the construction works area. The field of view depends on the properties of the camera. Figure 3 presents the positions of the cameras and the coverage of the construction works area.



**Figure 3: The range of the monitoring system in the construction works area**

In Figure 3a the dashed red line indicates the exact position of the construction works, while the orange and the magenta lines indicate the range of the first and the second camera respectively. Figure 3b provides a satellite view of the area. As shown in Figure 3, the view field of the two cameras overlaps in the wider area of the site as required for the proper 3D location of the monitored entities (Brilakis *et al.*, 2008).

Figure 4 illustrates successive instances of the construction works that present the dynamic environment of the site and the changes in it until the collapse of the ditch. The application of the proposed risk assessment methodology could prevent the occurrence of this risk. That is because the risk would be identified from the instance represented in Figure 4a, where there are seven risk components related to

that risk, namely: 1) the ditch, 2) the operating excavator, 3) the heavy truck, 4) the ground supporting device, and 5) the excavated ground. All these are parameters that may lead to the occurrence of the risk.



**Figure 4: Monitoring risk occurrence through video images**

Figure 4b illustrates another instance where a previously identified risk component is not present anymore (the excavated ground), while another risk component appears, i.e. the power generator next to the excavator. Moreover, the workers and other people in and close to the ditch constitute risk components not of the risk under study, but for the risk of injury due to the ditch collapse, which is closely connected to the risk under study. The succession of different risk components either belonging or not in the risk under assessment indicates the need for a constant and dynamic monitoring of the construction site or a timely response to potential risk occurrence. All these components are measurable through appropriate algorithms that can estimate 3D dimensions and distances between the risk components and in combination with the values of loads and soil stresses, which are also measurable it becomes feasible to assess the risk components and consequently the overall risk. By using appropriate algorithms, it is, even, possible to determine the soil material and its strength at a certain instance and use this data in combination with the rest available, in order to assess the risk of collapse (Brilakis *et al.*, 2005). The upper part of Figure 4c provides with a clear image of the ground underneath the asphalt; the determination of the soil condition along with the loads imposed to the ground both from the truck due to its weight and from the excavator due to its operation are perfect descriptors of the risk situation. However, since no dynamic monitoring and risk assessment has been actually performed in this case, the prevention of the occurrence of the risk was not achieved as shown in the down part of Figure 4.

## 5. Conclusions – Future Work

Risk assessment is a difficult task to perform, especially, in a dynamic environment where multiple risks exist at the same time. Therefore, another approach than the traditional ones, which are based on statistical and stochastic methodologies is required. Such an approach can be developed by the use of cutting-edge technologies in data collection allow a timely identification and measurement of all those elements that constitute the occurrence of a risk event. In order to define these elements, the concept of risk component has been introduced and defined as a constituent of risk that upon measurement can indicate the level of risk occurrence. The measurement of the risk component is achievable through vision-based tracking methods that can feed at real time the appropriate algorithms with the values of the

components in order to assess the overall risk. The ongoing research on this field is focused to the formulation of the appropriate algorithm for the integration of the values of the risk components to assess the overall risk, as well as, to synchronize existing algorithms and models to the approach discussed here in order to present a comprehensive framework for risk assessment.

## 6. Acknowledgements

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