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Project Vulnerability: State of the Art and Propositions for Future Framework Development

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This paper reviews research studies of vulnerability in different scientific disciplines. Here, we also challenge present research to incorporate this concept into the domain of project risk management. The formulation of vulnerability has usually common though contested meaning. It is explained as a degree to which a system is susceptible to harm and incapable to cope with its adverse effects. But the concept seems not fully operational. The challenges confronted to make it operational are to develop a robust method for its assessment; afterwards to promote adequate strategies for vulnerability reduction. Depending on a purpose of assessment as well as on specific environments, methods for vulnerability assessment do not show commonness among themselves, even not among the same scientific disciplines. The main objectives of this paper are to establish common ground for vulnerability and identify potential framework developments for project risk management.

1. Introduction

Integrating analysis of vulnerability into traditional risk management approach seems to be a promising step in effective risk response planning. According to number of scientific publications on the Web of Science, increasing interest in concept of vulnerability is present among various disciplines. It must be noted that just several works are present in a domain of industrial engineering and particularly in a field of project management [32]. Benchmarking more then 30 articles about vulnerability in different research areas, we have found that terms used on a conceptual level as well as application practices are still very vague.

The main purpose of this paper is to identify characteristics of vulnerability and key issues for its complete understanding in order to make this concept suitable for project environment. As we progress further in our research topic, we aim to build a coherent conceptual framework integrated with traditional project risk management methods that can be effectively used by project risk managers.

Having the mentioned purposes in mind, we start our paper by describing the project and its specific environment. Afterwards, we make a brief review on traditions of project risk management highlighting a need for introduction of vulnerability. The second and the third parts are dedicated to better understandings of vulnerability among different research areas and current approaches to assess vulnerability. The fourth part addresses vulnerability issues that need to be adapted for project environment. As this paper is conceptual framework, we conclude it with confrontation of challenges of the next step of our future research process.

2. Background

When considering project environment, it is essential to define what really project is. Among numerous ways to define project, this paper adapts a definition that "project is a temporary and unique endeavor undertaken to deliver result" [25; 21; 32]. Uniqueness and temporariness are the characteristics that make project different from everyday activities. Its uniqueness is mirrored in unique, specific target values, environment, resources, management styles and other parameters that constitute a project system. The temporariness is manifested through defined beginning and end [25].

Targeted values are project deliverables corresponding to service, product or extension of understandings, scientific contribution and other beneficial changes [29]. Deliverable is directly provided by project operational activities. As projects get more complex, managerial activities whose primary function is directed to distribution of information and keeping a project schedule on its track, have become fully inherent in project execution. Managerial activities are organized into five main processes: initiation, planning, realization, control and monitoring and project closure [25].

Project can be seen a system whose structure consists of several levels. While it is a specific system whose components are rarely linked in a way that causality can be easily explained, one of the most suitable methods to describe project system is using a system thinking method. This method is high exploratory and it enables

decomposition of a project from its smallest to its general parameters without loosing a sense of a whole. Thus, project can be structured [32] through:

- Project phases,
- Project values, objectives and goals,
- Project processes and activities,
- Project resources, actors, know-how, etc.

Considering this composition, we are able to understand a project mechanism. Going through its phases, project actors use resources and other inputs to perform project tasks and achieve deliverables. Projects consist of a large number of stakeholders, tasks, objectives and other components, and they all are correlated; that correlation is characterized either as physical, geographical, logical or cyber [18]. Because of numerous project components and their interdependent multinatural links, project by itself is a very complex system. Relying on a fact that a project is a system whose operations are influenced by conditions in other external systems, its complexity is even larger. The complexity, on one side, enables project to provide a unique and competitive deliverable. On the other side, it makes success more unpredictable.

On their way to provide a deliverable, projects are exposed to any internal and/or external risky events [3] that prevent them to reach their objectives. Thus, our research process is also focused on a negative connotation of a risk. Risky events hinder project to reach its targeted values. With increasing complexity and importance of projects, the need to manage risk arises naturally [21; 13]. Authors generally agree [25; 21] that project risk is managed through four-step process. Firstly, risk is identified and analyzed in order to plan a proper risk response strategy. Strategies are monitored and new risks are reassessed. For completing each step, numerous methods are developed. Still, many limits in their application are present. As this paper is not directly focused on a problem of project risk methods, more details can be found in a research paper written by Marle and Gidel. [22]. Our research highlights a shortage of existing project risk methods that are focused on a single risk and generally do not consider propagation of negative changes through a system. In order to bridge this gap, we go towards a current risk management tradition and include both multiple stressors and extent to which the effect is propagated until it reaches its final impact.

To open up a link between a cause and final impact, concept of vulnerability seems like a natural next phase in project risk management path of evolution. As the traditional project risk methodology is focused on a decision about risk mitigation in a time t_0 , vulnerability analysis tries to predict conditions of a system in times t_1,t_2, …t_n caused by a change in a time t_0. Integrating vulnerability in a traditional project risk methods will enable observation of a project in a whole by explaining the reason why some risks become risky events and how the effect of their occurrences is propagated through system until it changes the final project values.

Although the approach seems very promising, numerous limits for its implementation are still present. Firstly, it is hard to include or identify indicators that are relevant while defining one system. Also, prediction in time t_0 suffers low accuracy. Vulnerability runs even greater uncertainty because it estimates conditions somewhere in the further future trying to capture changes and shape future states.

Besides all the difficulties, the concept exists in numerous scientific disciplines. Some disciplines (E.g. Global Environmental Change, Disaster Management, etc.) have a long history of its application; but the concept is still not fully developed and consolidated. Thus, the main objective of this paper is to understand and make a foundation for development of a concept of project vulnerability. For that purpose, we benchmark different concepts to find commonness and differences in a language of vulnerability. The second part is dedicated to attempts and stakes to make the concept operational. Then, we translate identified issues into project environment and conclude the work with perspectives of our future research processes.

3. Vulnerability

A term of vulnerability is found in numerous scientific disciplines: from economy, engineering, environmental sciences, transport to social sciences. Although the term is widely theoretically elaborated, it still lacks on constant, common meanings. Because of its ambiguity, the concept of vulnerability is applied for many research purposes. As a result, various objectives, methods and contexts where applied have led to even greater divergences in its understanding. For example, research processes undertaken in pure natural systems differ from research processes in social or engineering systems. As there are no systems that operate independently from others, efficient research processes require consideration of vulnerability arising in interaction of multi-natural systems.

The word “vulnerable” has its root in Latin *vulnerare* that means: “to wound” or “susceptibility to being

wounded". The definition refers to harmful events or perturbations versus consequences. The word by itself has no meaning. It primarily lacks on answer to the question: vulnerable to what. Starting from the late 1980s, the vulnerability analyses have become more specific. Different contexts have defined different research purposes and directions. So, we can isolate two extreme approaches [11]:

1. Outcome-related. Research processes whose purpose is to identify potential negative effects that change predefined system values (e.g. vulnerability to famine);

2. Hazard-oriented. Research processes that follow this approach are used to identify one hazard and assess vulnerability to occurrence of different risky events that correspond to observing hazard (e.g. vulnerability to occurrence of extreme natural events such as Tsunami).

Besides the stake that different purposes require consideration of vulnerability in different manners, there is also a problem with understanding of its connotation. Vulnerability, by most authors, has a negative connotation. It is usually defined as a degree to which a system is susceptible to, and unable to cope with, adverse impacts [28; 23]. There are three key parameters present in all formulations: exposure, sensitivity and resilience.

1. Exposure is portrayed in stresses and perturbations that are experienced by a system. Stresses and perturbations are characterized in terms of magnitude, frequency, duration and areal extent of the hazard [8].

2. Sensitivity is a degree to which a system is expected to be modified by stresses.

3. Resilience defines how quickly a system recovers to a state defined as a well-being.

It must be noted that a generic meaning of parameters in certain research reports still have both negative and positive connotation [23; 9; 12].

It is clear that different contexts have different aspects on vulnerability independently of a research area. Our analysis of vulnerability starts from a domain of Environmental Sciences since it is the pioneer in this concept development. In a domain of Disaster management vulnerability is considered as a concept dependant on hazardous events. Later researches include assessment of vulnerability not particularly to extreme events but also to all stresses and shocks that somehow disturb system's well-being. The interest in extension of this concept of vulnerability, from extreme natural hazards to global climate change, has increased after the environmental adaptation and mitigation policies had become priority [15]. The research approach in this area views environmental system as a source of hazardous events versus social system as a subject to be affected. As the largest number of risky events associated with natural hazards cannot be prevented [10], there is little chance for adaptive strategies. Thus, the analysis of vulnerable elements and system activities is directed to choice of proper mitigation strategies and protection of preferred system values.

As changes in the environment are reflected on social systems and the linkage between ecological and social systems cannot be formulated in a "single universally accepted way" [5], there is no single defined way to choose approach, key parameters or corresponding indicators to define vulnerability. The choice depends on special needs and leading ideas that research follows. One group of approaches does not consider integrative socio-ecological system. The supporters of this thinking follow the idea that exogenous risky factors are distinguished from endogenous risky factors [11]. While exogenous risky factors are considered as incontrollable, endogenous risky factors constitute intrinsic vulnerability. Researches focused on exploration of factors that constitute intrinsic vulnerability as a property of one system have a relative long history in evolutionary path of this concept. Thus, factors of the intrinsic vulnerability are seen as a result of the absence of entitlements [14], institutional structures [8], and perception of insecurity [14] or as a result of a cumulative pressure of hazards and vulnerability [6]. The newest trend seems more promising and it switches a focus of observation from hazardous event to vulnerable element of a system taking into account coupled existence of pressure and vulnerability. This approach is dominant in works of Turner and his colleagues [28] where they also tend to describe how vulnerability propagates through the system over the time and what potential trade-offs of values are.

Evolution in research approaches in domain of Environmental Changes gives a major basis for better understanding of vulnerability in other contexts. Although other studies may look very distant, actually they share the same concept postulates. The question of differences is a question of research orientation.

The field of crime narrowly follows the idea developed in the field of natural disasters. Here, research process-

es tend to identify social facts that are somehow conceptualized in the occurrence of crime among individuals or groups of individuals [7].

Similarly to identification of crime factors, researchers in a domain of mental health tend to identify causes of different types of mental disorders [31]. The research process starts with identified disorder and defines patterns of stresses and shocks that cause observed disorder.

The aim of vulnerability analysis in a field of road transportation does not differ significantly from the concept in the mental health. As transportation systems are closely related to the concept of reliability, authors view vulnerability as a lack of reliability. Thus, the vulnerability of transport systems is defined as "susceptibility to incidents that can result in considerable reductions of road network serviceability" [4]. Very similar approaches and purposes are found in all infrastructural researches including information sciences too.

Finally, in a context of project management, the concept of vulnerability is on its beginning of the evolutionary path. As in other contexts, project vulnerability is defined as an extent to which a system responds to a hazardous event [34; 32]. The need for project vulnerability is introduced by Zhang in order to explain the project role in mediating between risk occurrences and final consequences. By understanding project and its malfunctions, this approach enables identification of project constraints to withstand or cope with effects of risky events. These findings are directed to development of adaptive strategies or strategies of vulnerability mitigation. Unlike the strategies for risk reduction in traditional project risk approaches, those strategies are focused on improvement in project management in order to protect system from multiple stresses and keep a system in a balanced well-being state counting on effect propagation.

While there are many differences in vulnerability approaches between contexts and within concepts themselves, certain commonalities exist. This is a synthesized list of issues that should be addressed while establishing a framework of project vulnerability:

- Vulnerability is multidisciplinary concept that consists of exposure (of an entity, sub-system, system) to stresses and disturbances, and difficulty in coping with them.

- Exposure is constituted of stresses, shocks and disturbances that are expected to have effects on an entity, sub-system or system. Sensitivity is defined as a level to which an entity, sub-system or system has been negatively changed. Resilience is a degree of recovery over the time.

- Mostly mentioned strategies for reduction of vulnerability are: adaptation and mitigation. Adaptation has evolved as a need to response to brand new sets of circumstances. Adaptation tends to extend a range of varieties with which it can cope and it is achieved through changes in management activities, organization and other settings. The strategy is very rarely applied in systems that are not policy-driven systems. Strategies of mitigation are evolved by experiences in dealing with known and understood stresses and disturbances. Its application is very present in natural systems and other systems that are exposed to unmanageable hazards; thus, mitigation is the only way to cope with.

- Analysis of vulnerability refers to a possible future harm. State of en entity, sub-system or system is always evaluated in a present moment.

- No vulnerability analysis provides a universal, accepted mechanism of key vulnerable parameters that could be used as a good base for designing methods to measure or assess vulnerability. It seems that all attempts to make this concept operational are very intuitive and based on particular objectives and questions addressed.

4. Assessment of vulnerability

Finding suitable metrics of vulnerability is a central research challenge. While there are many attempts, most of them are adapted for specific, particular research purposes. A single method has not been established yet.

Researching existing literature on vulnerability assessment, we have found that the first reason that it is hardly measurable is that the concept of vulnerability is not completely clarified. The word "vulnerability" by itself has numerous meanings and its semantic overflow produces numerous definitions. On the other side, no definitions explain mechanism of parameters that constitute vulnerability. Lack of theory guidance complicates its expression as a mathematical function.

Second important stake in establishing metrics is that vulnerability is not directly observable phenomenon [24]; its relevant parameters and corresponding indicators are hardly captured. Without indicators, metrics

does not exist. Considering that "vulnerability is complex, dynamic, compounding and cumulative, sometimes irreversible and frequently impossible to contain" [1], establishment of vulnerability indicators faces numerous limits. First, vulnerability of one system arises from interaction with other systems but also from malfunctions of its own system mechanisms. It makes a relevant area of observation very wide and requires a large number of indicators to be included. As large fields of observation include numerous indicators and most of them are impossible to be captured, the method suffers a risk being not holistic. In addition, indicators are often chosen according to certain needs and preferences of research sponsors.

Vulnerability indicators are functions of observable variables [15], thus a question of arguments used for their establishment is mandatory. The real difficulty is that element, group of elements, sub-system or system is vulnerable to multiple stresses so vulnerability is manifested in various trajectories. Some trajectories do not necessary lead to material damage as not all coping strategies are based upon financial or material investments.

The other significant challenge confronted is the implication of system governance to occurrence and mitigation of vulnerability. Successful methodology must not neglect those intangible variables, although their values are hard to be defined. Besides incorporation of intangible variables, vulnerability is a dynamic concept and its structure is changed over time. It means that the future system parameters are usually different from present parameters. Those changes are caused either by cumulative vulnerabilities, occurrences of new risky events, changes in trends or all of them together.

Being aware of potential limits and failures, certain authors found necessary to establish indicators and conceptualize them as standards [17; 30]. In most cases, vulnerability indicators present current state and estimate potential changes somewhere in the future [15]. We have found just few works on vulnerability assessment that concern dynamic characteristics of vulnerability [19].

The next important question while assessing vulnerability is a question of measurement scales. Since there is no single universal way of vulnerability definition, measurement scales are dependant on types and purposes of research processes [15]. It implies that the value of vulnerability can be expressed as an absolute measure. Absolute measure is a potential or actual financial or any material loss. Sometimes, its expression is an interval. As many authors follow the idea that assessment of vulnerability makes sense only if it supports making decisions, comparability is said to be a "key notion of vulnerability" [16; 33]. In that case, it is expressed as a relative number or excess over thresholds [20].

Although the vulnerability assessment is rather a theoretical concept, some steps to make it operational are established. Generally, the characteristics of steps are common and when applying them in the context of project, issues that need to be addressed are follows:

- The concept must be clarified on its theoretical level and defined in a way to be translated into a function.
- The vulnerability is contingent to certain hazardous events. Hazards can be either external or internal.
- Vulnerability is a multi-scale and multi-natural concept. It means that vulnerability can be assessed on different levels of a project system. A multidimensional nature is determined by different nature of damages and different units that are used for its expression.
- The method must not neglect dynamic characteristics of vulnerability.
- To make assessment of vulnerability valid, indicators and parameters must be carefully chosen. They must illustrate the present condition as a whole, as well as potential future states of a system.

5. Concept of vulnerabilityin a project context

Existing state of the art on project vulnerability proves that this concept, though attractive, has not been examined by many project researchers. Pioneer work on project vulnerability by Zhang [34] gave us the initial sight of project vulnerability; but his work remains on the level of conceptual understanding and attempts to identify sources of project vulnerability. Our thinking of vulnerability rests primarily on research conducted in Ecole Centrale Paris [21; 32]. The concept is particularly adapted to a context of project complexity. Although basic framework is established, further improvements are necessary for its wider application.

Relying on the existing knowledge on project vulnerability and vulnerability concepts in other concepts mentioned above, this work aims to provide a theoretical basis for its better understanding. Thus, we tend to incorporate consolidated terms into a coherent project

vulnerability framework; as we progress in our research, we aim to make this concept fully capable for application by project risk managers.

The common definition of vulnerability in other contexts is also suitable for projects. Thus, we adopt definition of vulnerability in negative terms: "degree to which a system is susceptible to and unable to cope with adverse effects" [28; 23]. Relying on this definition and common characteristics mentioned earlier in this paper, vulnerability is influenced by the ability of a system to absorb shocks and autonomy to self-organize in order to recover from the initial impact [11]. Vulnerability is manifested in potential deviations between planned/desired and actual project values. The deviations are results of system's incapability of neutralizing the effect or/and lack of awareness of impact propagation and potential strategies for its mitigation.

While traditional project risk methodology is interested in likelihood of a risk to become an event and its direct impact, vulnerability is dedicated to analysis of system's capacity to absorb shocks and adapt capacities to neutralize effects with minimal residual risks. In other words, traditional methodologies are used to analyze severity of a risky event in a time t_0 for a choice of a risk mitigation strategy; vulnerability analysis estimates global gravity of the chosen strategy in time t_1, t_2, …, t_n. This implies that the concept of vulnerability is an extention to traditional project risk methodologies. Thus, the first dimension of vulnerability is exposure. Exposure is defined as all risky events that are potentially hazard for project progress. While traditional project risk methodology considers if the risky event is internally or externally generated [3], vulnerability analysis is not interested in nature and sources of risky events. Exposure is used to define expectation that neg-

ative impact will affect the system. The magnitude of the impact is defined by the magnitude of a risky event, but its gravity is determined by sensitivity. Sensitivity is defined as nature and degree to which a project system is adversely affected by certain risky events. The sensitivity is expressed by desired value and level of tolerance that is called threshold. If the negative effect exceeds threshold, project is said to be incapable to self organize or adapt to that impact. The system requires new measures to be applied. According to the whole project adaptive capacities, decision maker tends to choose the one strategy that effectively recovers a system from failures. The adaptive capacity is the third dimension of vulnerability: non - resiliency.

According to the mentioned definition, vulnerability is a function of: exposure, sensitivity and adaptive capacity (Eq. (1)). Exposure and sensitivity constitute potential impact (Eq. (2)). Thus, vulnerability is a function of potential impact and adaptive capacity (Eq. (3)).

$$V = f(E, S, AC) \quad (1)$$

$$PI = f(E, S) \quad (2)$$

$$V = f(PI, AC) \quad (3)$$

Where V is vulnerability, E is exposure, AC is adaptive capacity, a PI is a potential impact.

Those simple conceptual functions are expressed just to describe the way vulnerability elements are related. Nevertheless, the functions are not directly operational.

Although the meaning of term "vulnerability" is somehow theoretically understood, it is not operational as long as its measurement system is not established. Taking into account that vulnerability is not directly observable phenomenon, measurement system cannot be established without defining the purpose. Besides many reasons why vulnerability is measured [15], the purpose of our further research is outcome-oriented. Thus, our tendencies are to identify vulnerable project elements, tasks and processes and propose strategies that mostly contribute to the balance of project parameters. As there are polemics about parameters that define project success [2], we claim that they all can be captured in a "Golden Triangle" that consists of: schedule, cost and quality.

To make a complete project vulnerability framework, we need to identify relevant indicators that can explain concept in a whole. A structure and key indicators, in dynamic and complex systems such as a project is, are hard to be captured. In order to catch a sense of whole, we propose to avoid a traditional thinking of breaking down a problem and observe project through system thinking. System thinking is a heuristic discipline [27] for seeing a project system through multiple levels and interrelationships between components that constitute those levels. Resting on the work by Vidal [32], project as a system is separated into phases (Figure 1). Phases consist of certain project values and objectives that are to be achieved. Project values and objectives are provided through operational tasks managed by project management processes. And finally, management processes and operational tasks are performed by resources and different types of inputs. Observing a project system in this way allows us to underlie structures of project components and their interactions that shape conditions under which some types of risky events become likely [27] and opportunities to cope with their adverse effects.

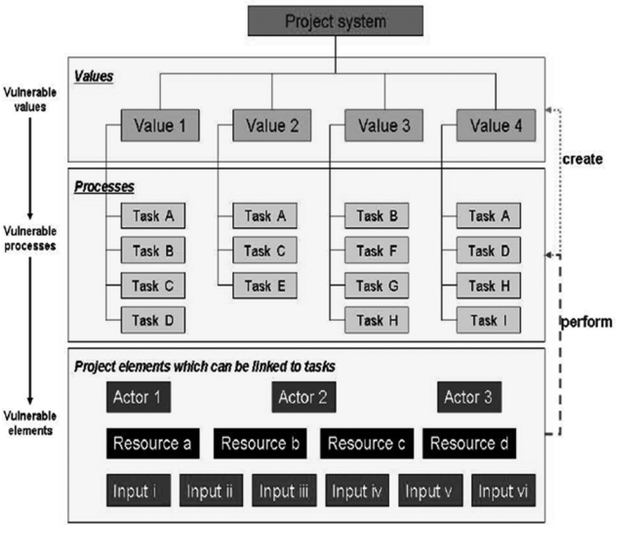

Figure 1. *Steps in vulnerability identification using system thinking method [32]*

5. Conclusion and perspectives

This work is primarily focused on better understanding of a concept of vulnerability in order to define project vulnerability framework. For that purpose we have presented a broad state of the art on the basis of different aspects of vulnerability. As concept is considered as theoretical, we have reviewed current attempts and stakes to make it operational. Resting on commonness in vulnerability concepts we synthesized its characteristics:

- Vulnerability is an extent to which a system is incapable to cope with negative effects;
- t consists of: exposure, sensitivity and resilience;
- Vulnerability is changed over the time and not directly observable phenomenon;

- The concept lacks on metric system. The difficulty to build it arose from difficulties to identify relevant indicators of vulnerability.
- Concept of project vulnerability is partially understood and developed.

Indeed, this broad state of the art and a proposition of a new conceptual framework are trying to make clear issues on project vulnerability. Identified underlined structure of a concept opens up new questions that are focus of our future research:

- Identification and classification of factors that influence project vulnerability.
- Finding consensus about crucial vulnerability factors.
- Identify most common trade-offs of project values.
- Compare preferences in trade-offs and other vulnerability elements due to subjective and other specific issues that influence perception of vulnerability.

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