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Cognition and Cognitive Dynamic Systems Concepts and Applications in Project Risk Management

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Abstract

Cognition is the brain's ability to perform high-level functions including understanding and information processing. In general, cognition is considered analytical rather than emotional. Cognitive models are mathematical representations of issues that are not necessarily mathematical. On the other hand, risk analysis and management is a process of defining factors or parameters that are mildly to severely dangerous for a given system involving businesses or individuals. Recently, research and investigations have explored the potential of utilizing cognitive models in risk management and analysis in order to better clarify risk factors in a system and control risk resources. In this paper, fundamentals of risk management and cognitive dynamic systems are discussed, and applications and various implementations of cognitive systems based on real-life examples are introduced.

Keywords: Project Management; Risk Management; Cognitive Dynamic Systems; Cognition.

1. Introduction

Risk analysis is the systematic research of uncertainties and risks encountered in many areas such as business, engineering, public policy, and information technology. Risk analysis seeks to identify risks faced by an institution or business unit and to comprehend how and when the risks and issues occur. Also, risk models attempt to estimate the impact of financial and otherwise adverse outcomes. The target and ultimate goal of risk management is to seek solutions and take actions that mitigate or hedge these risks. Risk management and decision making are more difficult in today's complex and rapidly changing environment than ever before.

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Over the past few years, both decision optimization under risk and risk management in decision making have progressed considerably. Decision support systems, risk analysis systems and emergency response systems are playing significantly more important roles in organizations in every discipline including health, business, engineering, education, and finance. At the same time, organizational decision makers and risk response officers are seeing increasing requirements for advanced knowledge, previously successful experiences, and intelligent technical conditions to enable and support better risk analysis and decision making.

The process of risk identification involves finding major potential sources of risk for a specific project. A risk management plan identifies tasks, project team roles, and responsibilities. Previous experiences can provide guides (usually implemented in the form of checklists) for adverse situations, as well as the organization's ability to cope with them [1]. Consequently, the applications of intelligent procedures and technologies are improving the functions and performance of these systems. This review article, as the title suggests, aims to offer a thorough introduction and systematic overview of various aspects of the field, including both theorems and applications. The methods, models and systems proposed in this article can be used by a large number of organizations in related applications. Business managers will also directly benefit from the information outlined here [2]. Recently, researchers used complicated models inspired by human cognition which showed more reliable, robust solutions for decision making and risk management systems, which will be discussed later.

2. Risk

Risk can be defined as an event that is uncertain and has a negative impact on some endeavor [3]. The word risk derives from the early Italian word risicare, meaning "to dare," indicating that risk is a choice rather than a fate. In general, risk is defined as "exposure to the chance of injury or loss; a hazard or dangerous chance." In statistical decision theory, risk is defined as "the expected value of a loss function." Therefore, various definitions of risk reveal that we expose ourselves to risk by choice. Risk is a measure where likelihood is understood as a "qualitative description of probability or frequency," but frequency theory depends on probability theory, which explains that risk is a probabilistic variable [4]. Risk is also the expression of the likelihood and impact of an event with the potential to influence the achievement of an organization's objectives. The phrase "the expression of the likelihood and impact of an event" implies that, as a minimum, some form of quantitative or qualitative analysis is required for making decisions concerning major risks or threats to the achievement of an organization's objectives. For each risk, two calculations are required: its likelihood or probability, and the extent of the impact or consequences [5]. Some organizations refer to risk as a function of the probability (chance, likelihood) of an adverse or unwanted event, and the severity or magnitude of the consequences of that event [6]. In the PMBOK ® Guide – Fourth Edition, "project risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives.

3. Uncertainty

Merriam-Webster defines uncertainty as "the state of being uncertain; doubt." Another definition according to Decision Making under Uncertain and Risky Situations is "the inability to assign probability to outcomes," and risk is defined as the "ability to assign such probabilities based on differing perceptions of the existence of orderly relationships or patterns” [7].

Uncertainty is not measurable, and so cannot be quantified. Uncertainty occurs in circumstances that cannot be analyzed because they are too irregular and unique. Merriam-Webster defines risk as “possibility of loss or injury; peril,” and uncertainty as “indefinite, indeterminate and not known beyond a doubt.” The difference between risk and uncertainty is that risk indicates a positive probability of something bad happening, while uncertainty does not essentially suggest a value judgment or ranking of the possible outcomes. Frank H. Knight established the economic definition of these terms in his landmark book Risk, Uncertainty, and Profit (1921):

- Risk is present when future events occur with measurable probability.
- Uncertainty is present when the likelihood of future events is indefinite or incalculable.

4. Risk Management

4.1. Project Risk Management Definition

Risk management is about developing strategies by using analysis to reduce or improve risk. According to the PMBOK Guide [8] the objectives of project risk management are to increase the probability and impact of positive events, and decrease the probability and impact of negative events in the project.

4.2. The Risk Management Process

Project risk management helps to identify and prioritize risks before their occurrence.

- Identifying risks
- Analyzing the risks
- Assessing and evaluating the risks
- Managing the risks
- Monitoring and reviewing the risks
- Communicating, consulting with stakeholders

4.2.1. Identifying risks

There are several methods for risk identification. Comprehensive databases of risks on past projects can be very helpful, and often access to this knowledge requires brainstorming by the project team. Besides technical expertise and experience, a project team’s contribution and face-to-face communication are essential to effective risk identification [9].

4.2.2. Risk Analysis and Assessment

Risk assessment is the process of gathering, combining, and presenting evidence to support a statement about that risk. Risk analysis can be quantitative, qualitative, or a combination of both [10].

4.2.2.1. Qualitative Risk Analysis

Qualitative risk analysis orders the identified risks using a rating scale. Risks are scored based on the probability or likelihood of occurrence and their impact [11]. Qualitative assessments produce non-numerical estimates of risk [10].

Figure 1: The cycle of risk analysis and management is figured where the concept of cognitive dynamic systems and models is utilized. The proposed novel model contains risk management and planning, cognitive model-based design, risk identification, risk assessment prioritization, cognitive model-based quantitative risk analysis, risk response planning and finally cognitive model-based risk tracking & control. In this cycle, the cognitive-based steps are shown in black.

Probability and Impact Matrix

It helps to decide which risks need more attention.

- Probability: The probability of a risk can range from just above 0 percent to just below 100 percent or it can be a number between 0 and 1. It cannot be 100 percent, because it then becomes certainty; it cannot be 0 percent, or else it is not a risk.
- Impact: A risk has a negative impact, with a variable size of impact.

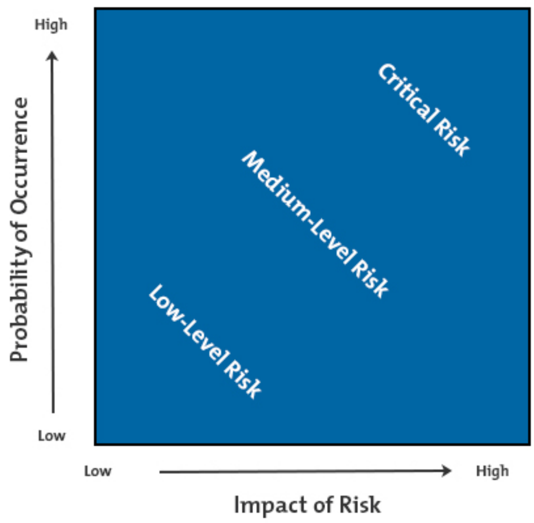

Figure 2: The Risk Impact/Probability Chart (Image courtesy: mindtools.com)

Pareto Diagrams

Pareto diagrams are another method for displaying the roots of uncertainty or impact in descending order. These analyses can provide guidance for managers to reduce, mitigate, and manage the sources of uncertainty [12].

Failure Mode and Effect Analysis (FMEA)

The FMEA method starts by considering the risk events and then proceeds to predict all possible effects in a chart form. FMEA can be a qualitative analysis, but also can be considered as quantitative method when mathematical failure rate models are combined with a statistical failure mode ratio database [13].

4.2.2.2. Quantitative Risk Assessment

After assessing the risk factors qualitatively, we quantify these by screening activities to be the most significant. There are many available methods and tools for quantitatively combining and assessing risks. We briefly discuss some of those here.

Multivariate Statistical Models

Multivariate statistical models, also known as regression analysis, are derived from historical data. These statistically based methods require a large database of projects. When data are not enough for direct statistical methods, computational methods such as resampling and bootstrapping are used [12]. Regression analysis is a technique for measuring the relationship between an outcome variable and risk factors or confounding variables [14].

Ishikawa (Fishbone cause and effects diagrams)

The cause and effect diagram can be used to explore all possible or actual causes (or inputs) that result in a single effect (or output). This tool can be used for identifying areas where there may be problems, and also to examine causes of risks.

Sensitivity analysis

Sensitivity analysis is where different variables are introduced to show the impact on the risks. This analysis shows what would happen if predictions fail to materialize. Sensitivity analysis is being used to define which variables have the greatest impact on the risk.

Monte Carlo

Monte Carlo is a numerical technique which simulates possible results by substituting a range of values a probability distribution [10]. It is used to replace uncertain parameters in models and calculations with probability distributions that represent the natural variability and knowledge uncertainty in those inputs [10]. These output distributions can be subjected to statistical analysis to inform decision making.

5. Cognition

Human cognition refers to high-level brain functions that deal with understanding information, processing it, and retaining knowledge. Cognition in particular deals with logical or analytical aspects as opposed to emotional aspects. From Heraclitos in the 5th century BC to contemporary psychophysicists, neuroscientists and psychologists have always believed that perception is a representation of the world entering the mind through the senses. In modern neuroscience, perception is widely assumed to be reducible to the effects of sensory stimuli upon dedicated receptors, pathways and nerve cells [15]. The perception action cycle (PAC) has its origins in the 1920s when Jacob von Uexküll described a sensory-motor cycle observed in the behavior of primitive animals. As described by Joaquin Fuster, the perception action cycle is more complex and is based in neurobiology rather than behavioral observation. The cycle, which determines an animal’s actions, begins when the animal perceives its immediate environment through its senses. The act of perception includes recognition and updating memory, with the goal of building a representation of the world. This process takes place in the posterior cortex of the brain. Next, the animal’s behavior or selection of actions is based on the perceptions of the environment that the animal has built. These actions then act on and change the environment and therefore change the animal’s subsequent perception of its environment. The cycle is completed with these new perceptions and the actions based on them.

Fuster describes five cognitive functions: perception, memory, attention, language, and intelligence. Perception relates to one’s understanding of the world or environment around them. It goes beyond simple sensory inputs and includes functions of memory and attention. In neurobiological terms, perception involves the activation of cognits, or cortical networks, that make up memories. Memory deals with the capacity to retain information about oneself and one’s environment. This information includes both conscious and unconscious knowledge, the mental traces of experience, past events, learned facts, and relationships between facts [15]. The formation of memory (sometimes referred to as memory encoding) involves the formation of cortical networks and the strengthening of synapses that form these networks to create associations by which memories can be retrieved. From an information-processing point of view, the function of memory is to encode and store the received signal and then recall this information when required [16].

Attention refers to the efficient use of resources when dealing with a task. It is displayed in the selective allocation of neural resources to that task through excitation and inhibition of cortical networks. The role of attention is to select one of the cortical networks at a time and to keep it active for as long as it serves a cognitive function or the achievement of a behavioral goal [15] [17]. Unlike memory and perception, there is no separate structure for attention as it is evident in processes rather than localized areas of the brain. From an engineering point of view, the attention provides for the effective, efficient, and well-organized utilization of computational resources in a cognitive dynamic system, so as to avoid the information overload problem [16]. While it is not very difficult to define language as a set of rules for communication, it is not necessarily as clear how it fits in with the other four functions of cognition. Essentially, the mechanism of language is localized in perceptual and executive areas of the cortex [15].

Perceptual areas are responsible for understanding incoming speech or written words. On the other hand, executive areas are responsible for transforming complex ideas into understandable outgoing speech. Intelligence is the most complex of the five functions of cognition as it is distributed throughout the other four functions [15]. Intelligence is the ability of a cognitive dynamic system to continually adjust itself through an adaptive process by making the PAC respond to new changes in the environment so as to create new forms of action and behavior in the actuator [17]. Specifically, the function of intelligence is to enable a decision-making algorithm to select the optimal solution [16] [18] [19].

5.1. Cognitive Models

The design of cognitive models is inspired by the human brain and cognition. These models, so-called cognitive dynamic systems, are formed based on five cognitive pillars proposed by Fuster shown in Figure 3. In a cognitive model, the function of the perception-action cycle is to generate information by receiving and processing signals from the environment. Thus, a cognitive dynamic system such as cognitive radar must be equipped with an appropriate set of sensors to receive signals and learn from the environment [17].

The short- or long-term memory is the second component of a cognitive model. The executive and perceptual memories within cognitive system are analogous to long-term memory in the human (or animal) brain. In the human brain, long-term memory is responsible for storing information so that it can be recalled and used by working memory.

Recently, a new architecture of neural networks called Long Short Term Memory (LSTM) of Recurrent Neural Network has been paid attention by so many researchers in different fields as this architecture enables engineers to process and then predict the sequence of information such as time-series. Using several sigmoid (logistic) functions and mathematical information, the memory block has been designed for this deep learning architecture [21, 22, 23].

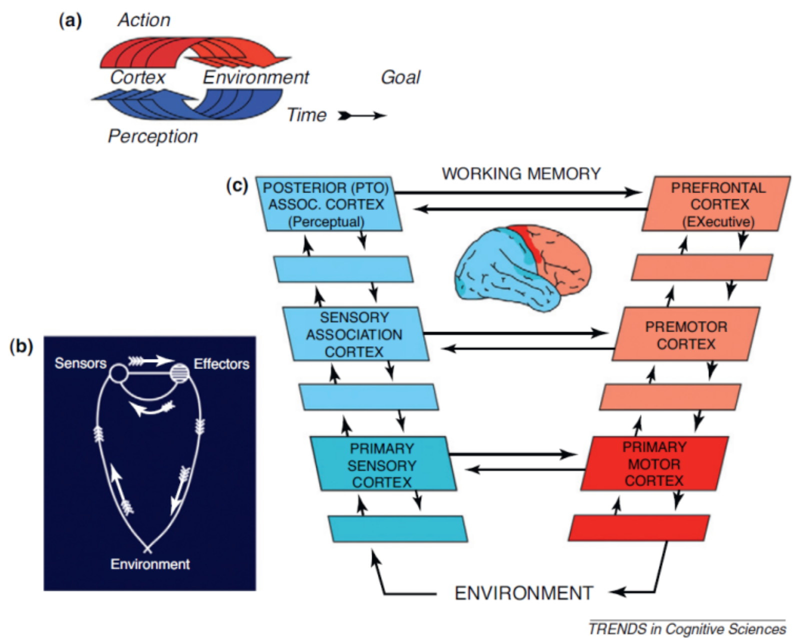

Figure 3: Schematic structure of the cortical perception-action cycle around a diagram of the human brain [20]. (a) Basic diagram of the PAC toward a goal through cortex and environment, (b) basic diagram of the sensory-motor cycle from Von Uexküll, with the internal nervous feedback from efferent to sensors, (c) general view of the connective framework of the PAC in the primate cortex.

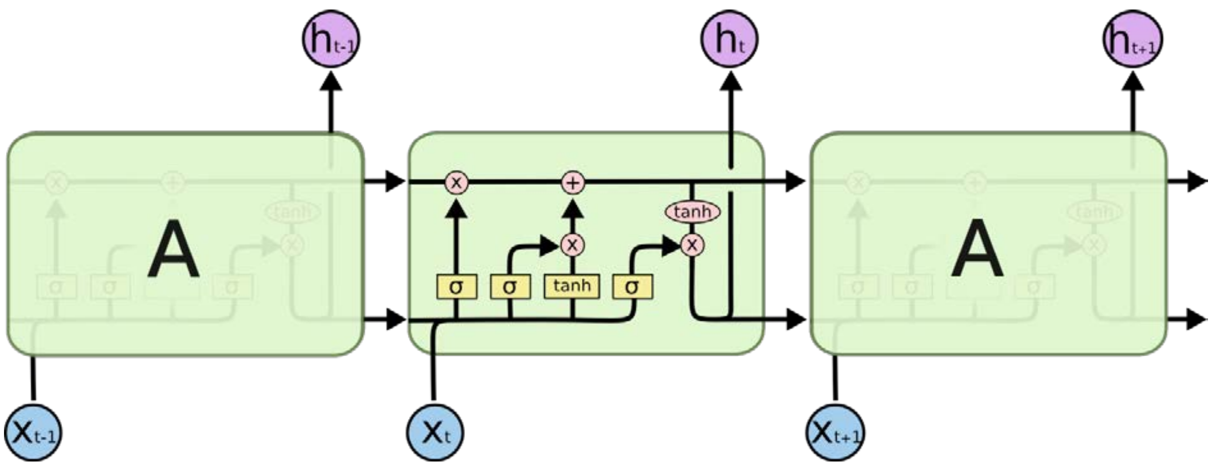

Figure 4: The repeating module in an LSTM contains four interacting layers (Image courtesy: Christopher Olah) [23]

The next module of a cognitive model is attention, which refers to the efficient activation of cognits for a specific task. There is no specific structure responsible for attention in the human brain; rather, it is a process or mechanism that is distributed throughout the perception-action cycle and memory structures. In the human brain, attention is responsible for activating relevant cognits in memory while inhibiting other cognits. Similarly, attention is used in cognitive radar to localize a search area when matching a set of abstract features to a signal in the system-modal library or in the transmit-waveform library, using the so-called "explore-exploit" strategy [24,28,29]. The block diagram of cognitive radar (which is highly similar to human cognition) is shown in

Figure 5 [21, 22,25].

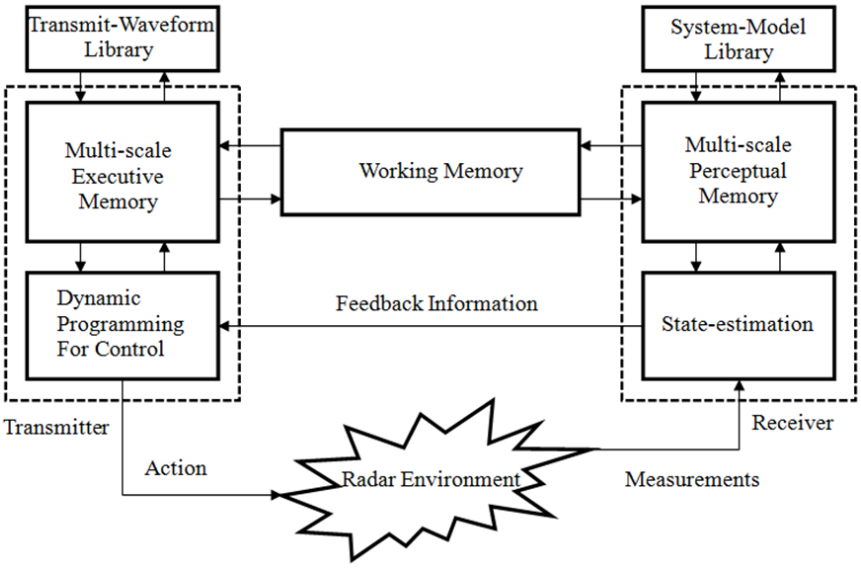

Figure 5: Block Diagram of Cognitive Radar

5.2. Cognitive Models in Risk Management

Ranyard and his colleagues [26] explained that cognitive models assume that the level of cognitive processing is determined by the content and importance of the problem and that thinking is dependent on the problem domain. Table 1 summarizes certain cognitive models, with their main concepts and predictions. Karayev and his colleagues [27] described a cognitive approach in the development of innovation management models for a company called CIM. They showed that a cognitive approach is a method of studying and managing situations based on the formation and study of cognitive models (cognitive charts).

Table 1: Prominent concepts and predictions for cognitive models

Theory	Prominent concepts	Predictions
Fuzzy-trace theory	Gist extraction	Risk aversion for gains
	Fuzzy processing	Risk seeking for losses
Elaboration theory	Elaboration	Increasing inconsistency in risk attitude with increasing elaboration
Probabilistic mental model theory	Reference class	Risk attitude depends on reference class
Positive-negative asymmetry	Positive bias Negatively effect	Not related to risk attitude (mainly in message compliance studies)

A cognitive chart is a structure (network) of cause and effect relations between the components of the system under survey and its surrounding environment, reflecting the conception of management person(s) about the structure and functioning of this system [29,30]. The components of a cognitive chart are (1) basic factors and concepts characterizing the system and its surrounding environment according to the management person(s), and (2) cause and effect relations between basic factors. A specific feature of the cognitive modeling method setting it apart from traditional methods is the possibility of conducting multi-factor and multi-criteria analysis and management of development of ill-structured situations (combining vitally important stages of divergence, convergence and transformation of project cycle (J. Jones)) that is not possible through traditional mathematical calculations. They argued that the need for development of appropriate methodology for developing cognitive models of CIM could result in a general scheme of this methodology shown in Figure 6.

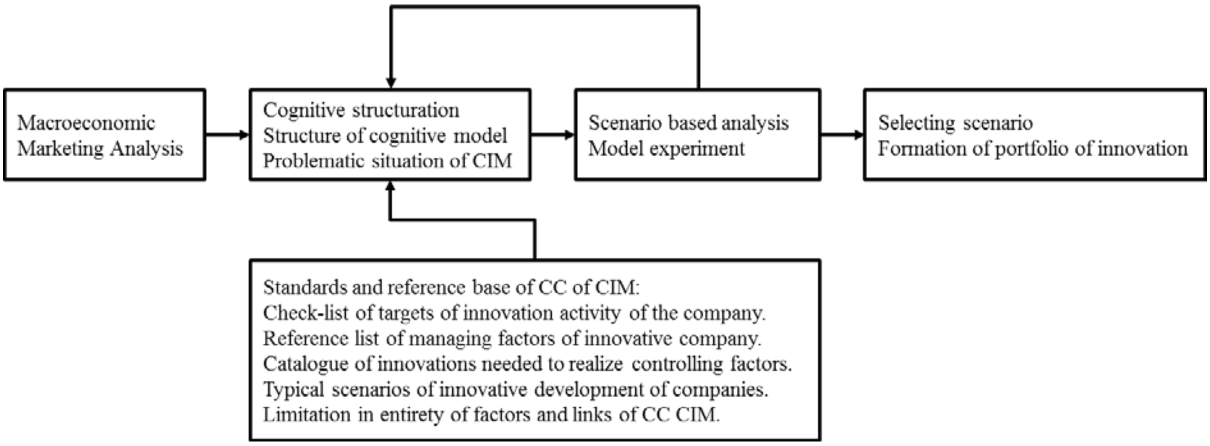

Figure 6: Cognitive CIM models development methodology chart

6. Conclusion

Cognitive systems, risk management, and the importance of utilizing cognitive models in risk analysis systems were discussed in this paper. Cognitive systems inspired by human cognition provide flexibility and realistic modeling rather than traditional system design. Because risk analysis a process of defining factors or parameters of systems is complicated nowadays due to more sophisticated blind sources affecting the system behavior, using the cognition and cognitive models in risk analysis and management can potentially reveal source of risks and assist risk analysts and managers to fully understand the system. To conclude, the feasibility of performing multi-factor and multi-criteria risk analysis and management in cognitive model-based risk analysis is higher than classical methods while unknown risk resources can also be detected.

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