USING MARKOV DECISION PROCESS FOR CONSTRUCTION SITE MANAGEMENT IN CAMEROON

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Abstract. Building construction sites are enclosed and restricted environments with minimal space to maneuver objects. Thus the organisational management of cost control, time and quality of construction projects is a huge challenge. Methods of project management commonly used by companies in developing countries are essentially planning schedules. Often, these methods are based on the assumption that complete knowledge of the project is known. Managing a construction project does not only depend on site factors but also on external factors such as different stakeholders involved on the project and weather conditions. As a result construction projects are often exposed to many vulnerable conditions leading to risks and uncertainties that generate decision problems affecting decision-making. In order to help project managers to optimize the construction management of the project, interactions or relationships between different vulnerabilities in a construction site have been identified and categorized. Based on the categorization, a methodology based on the Markov Decision Processes (MDP) was developed for optimising construction site decision-making affected by vulnerabilities. MDP are powerful analytical tools used for sequential decision-making under uncertainty, widely used in many industrial and manufacturing applications.

Keywords. Construction site management, decision-making, MDP, optimisation, uncertainties

Introduction

Over 30\% of construction projects in developing countries including Cameroon faced major problems during execution [1]. Some of the problems include delays, cost overruns, site accidents, re-work, labour under-utilisation, construction materials and energy wastages. These problems are quite common on sites with no proper functioning organisational strategy. Construction sites are characterised by a diversity of stakeholders, a multitude of standards and regulations, many spatial constraints between storage materials, management of flows, a high number of workers or tradesmen, constant changing of equipment and/or plants, and modifications to plans and technical specifications to meet the ever-changing clients’ requirements. These

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factors have effects on decision-making which often triggers change in projects’ objectives, deadline, costs and quality [2].

To address this complexity and challenge, this study aims to provide a suitable tool for the management of construction projects in Cameroon, that can potentially enhance construction professionals’ abilities to make optimal decisions resulting to best outcomes between projects’ cost, time and quality constraints.

1. **Analysis of construction sites decision-making factors**

A construction activity is a process that can be summarized using five main dimensions: i) structural dimension characterized by different actors, ii) a physical dimension characterized by the sub-works and tasks of the proposed work; iii) a temporal dimension that includes the life cycle of the project, iv) economic and technical dimension which incorporates the concept of quality and cost based on the technical option chosen, and more recently v) an environmental dimension that incorporates the project’s environmental impacts. The construction site is inscribed in time and space. It can be modelled as a set of materials, equipment, manpower or labour, methods and means of interacting in a specific environment to create a project with well-defined specifications. This complexity is similar to problems whose solutions can be derived from solving Markov decision processes.

1.1. **An organisational construction site modelling**

The organisational structure of a construction allows a rational and objective planning of human resources, materials and production resources of a company. This scheme includes the site installation, general planning, production management planning, labor and financial management planning, and its follow-up which is divided into two phases: measurements phase (reality/forecasts) and regulation phase (minimizing the differences observed). All dimensions and operations deployed on the same space create a dynamic and complex decision-making process in the construction site (see Figure 1).

![Figure 1. A construction site organization modelling](image-url)

The main elements of managing construction sites commonly used in Cameroon are: tasks coordination based on planning which consists of constantly seeking the best
way to optimally use site resources. Site information often documented in site log books and site meeting report books often provide useful information in revising schedules for use in construction site management. The study of decision problems in a construction site is often based on uncertainties resulting from unplanned and frequent irregular changes or modifications made about construction activity. In fact, over 45% of the time spent by workers on construction site is non-productive, and half of that time is due to inefficiency in management [3]. Thus, the choice of number of workers with manpower mainly from the informal sector, the composition of the teams by trade and the time of its implementation are important considerations of human resource management in an uncertain environment such as the construction site [4, 5]. Table 1 provides a summary of issues and decisions vulnerabilities encountered on a construction site.

Table 1. A summary of decisions and uncertainties encountered in a construction site

<table>
<thead>
<tr>
<th>Building elements</th>
<th>Decision-making problems</th>
<th>Key uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Choice of suppliers stock management</td>
<td>availability (deficiency), losses, quality, site containment</td>
</tr>
<tr>
<td></td>
<td>Materials type</td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td>Acquisition type</td>
<td>Failures, unknown yield, uncertain financial means</td>
</tr>
<tr>
<td></td>
<td>storage facilities and location arbitrary recruitment</td>
<td>composition of teams per trade poorly controlled</td>
</tr>
<tr>
<td>Manpower</td>
<td>Lack of adequate understanding between training and the real market needs.</td>
<td>Accidents, illness, strikes, unavailability, poorly controlled performance.</td>
</tr>
<tr>
<td>Methods</td>
<td>Tasks scheduling Fabrication technique</td>
<td>Practices, regulations, attitudes</td>
</tr>
</tbody>
</table>

Problems on a construction site are numerous, confused, dynamic and conditional, where the consequences of bad decisions are transformed into new uncertainties necessitating restorative decisions. The decision-making approach adequate to solve these fluctuating problems requires more sophisticated tools than simple probabilistic or multi-criteria approaches. We will use the Markov decision process based on a sequential approach under uncertainty. The relevance of the use of this method on a construction site is justified by the sequential character of decisions problems encountered in this domain. A conventional construction operation begins with the statement notification and ends with the closing of the project. The project has a defined period starting from the date of notification to the contractor to commencement of execution of the project. Furthermore, any construction project can be broken down into elementary tasks organised by scheduling technique. Each task can be associated to an entity including a start date, an end date, materials, equipments and labor resources. An example of decomposition diagram is presented in section 1.2. On the other hand, there is an interaction between the problems encountered on a construction site. In fact, during a construction operation, all preferences and choices influence on future operations. For example, lack of materials automatically creates unproductive hours for labour which can cause delays in the execution of sub-structures or the structure.
1.2. Construction management and decision-making

As discussed in section 1.1, the construction project can be broken down into several sub-works represented by $so_k$, each of which can be decomposed into elementary tasks $PE_{ki}$ (Figure 2). A task is an operation that consumes resources including materials, equipment, labour and technical implementation. It is also characterized by dependent resources parameters consumed such as the task execution time $D$, the task cost $C$, and the task execution quality $Q$. They constitute the three main criteria and will be aggregated into a single criterion for use in making alternative choices.

![Figure 2. Decomposition diagram of sub-works and elementary tasks [6]](image)

The Markov Decision Processes models are among the tools for the development of modern decision-making theory [7] for use on construction sites where many actors and tasks must be planned and implemented for optimum results. The context of this environment is modelled by a set of states controlled by a set of actions influencing the dynamics of each state transition; states being allocated to the construction schedule progress rate and the accounts payment rate (Figure 3). The $K$ potential actions that involve uncertainties include: choosing experienced suppliers, materials inventory management; preventive equipment maintenance establishing, recruiting moderately skilled labour and gradually strengthen its training; resort to outsourcing of skilled labour, choosing the number of workers in accordance with the work quantity, choosing arbitrarily the number of workers,…etc.
Thus, a construction management process will be modelled by a quintuple $(S,A,T,p,r)$, where:

- $S$ is the states set defined by a finite set $\{s, t \in T\} = \{C, Q, D\}$;
- $A$ is the actions set, defined by a finite set $\{a_1, \ldots, a_K\}$;
- $T$ is the time domain (assumed finite);
- $p$ represents the probability of transition between states;
- Finally, $r$ is the reward accumulated from the moment $t$ to moment $t+1$.

**Figure 3.** A construction management process modeling

MDP solutions are policies $\pi$ (strategies, decision rules) that specify the decision maker’s action for each stage for possible future situations, and optimise a given performance criterion (finite, weighted, total or average). The purpose of the model is to solve a decision problem. The decision analysis model takes as input the decision problem parameters, follows the intermediate steps (analysis, choice, preference, synthesis) and returns as output the optimal policy. The risk assessment made by the decision-maker from experience or perception, allows the cost to be assigned a potential chance. For example, a heavy rain will have a significant impact during concrete pouring, but has less effect on a window installation. The decision tree is a predictive model based on a graphic and explicit sequence to be pursued for decision making. The set of states of our system is defined by the triple $(C, D, Q)$, selected from an assumed finite set $T$ (without which it is in a state of failure). Then,

$$S = \{(C,D,Q)_k, k = 1,2,\ldots,N\} \cup \{S, failure\}$$

In this study, we work in a context of finite space of individual decision, where the decision-maker has access to all information on the process controlled. We use the preference criteria from MDP under uncertainty. The decision tree presents decision analysis with subjective probabilities to aggregate existing historical facts, experience, and learning for probabilities evaluation, while respecting consistency and constant
constraints [8]. For transition functions, we use the quantification methods and classification of approximate particular risks:

- Extremely likely \((0.6 \leq p \leq 1)\);
- Very likely \((0.3 \leq p < 0.6)\);
- Probable \((0.1 \leq p < 0.3)\);
- Unlikely \((0 \leq p < 0.1)\).

The immediate reward due to the choice of an alternative is:

\[ u(a) = r(a,s) = c_c \alpha_1 + c_d \alpha_2 + c_q \alpha_3; \sum_{i=1}^{3} \alpha_i = 1 \]  

(1)

Where:
- \(c_c, c_d\) and \(c_q\) are rewards associated with the three criteria;
- \(\alpha_1, \alpha_2\) and \(\alpha_3\) are the corresponding weights.

This reward does not include the costs of hazards to occur due to the choice of alternative \(a\). For a state \((C,D,Q)\) and an action \(\tilde{a}\) subject to a random probability \(p\), the probability of transition to a state \((C',D',Q')\) characterised by task 2 is:

\[ P((C,D,Q),a,(C',D',Q')) = p((C',D',Q')) \| (C,D,Q),a \]  

(2)

\[ R((C,D,Q),a,(C',D',Q')) = c_c \alpha_1 + c_d \alpha_2 + c_q \alpha_3 = r((C',D',Q'),a(C,D,Q)) \]  

(3)

The variation in states are measured relative to the planned path, so it is possible for the decision-maker to know the state of the system through indicators (progress monitoring), making it possible to know in real time the different paths. In the initial state, quality, cost and time are assumed to be zero. Note that a positive reward is associated with a gain, while a negative reward is associated with a loss. The optimal decision policy is one that maximizes the reward.

2. Application

2.1. Data presentation

The application relates to the structural work, which is decomposed into sub items including earthworks, foundations and paving, elevations, frame and cover. In this regard, four possible actions are considered:

- choosing the number of workers in accordance with the amount of work (BGM);
• choosing arbitrarily the number of workers (MGM);
• choosing experienced suppliers (BCF);
• choosing the nearest suppliers from the construction site (MCF).

We assume that all actions that are not mentioned are considered the best of their
statements (not subject to any hazard) and do not contribute to the system dynamics. The
main alternatives that are available to site manager between any two tasks can be
summarized by the set:

\[ \{(BGM, MCF); (MGM, MCF); (BGM, BCF); (MGM, MCF)\} \]

isomorphic to \( \{1, 2, 3, 4\} \).

Considering the impacts only in financial terms, the rewards arising from the execution
of the task for each alternative are summarized in Table 2.

**Table 2. Rewards arising from a choice of alternative**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Reward on failure (CFA francs)</th>
<th>Reward on success (CFA francs)</th>
<th>Gain planned (CFA francs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost</td>
<td>Time</td>
<td>Quality, Time, Cost</td>
</tr>
<tr>
<td>1</td>
<td>-10 000</td>
<td>-5 000</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>-10 000</td>
<td>-5 000</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>-10 000</td>
<td>-5 000</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>-10 000</td>
<td>-5 000</td>
<td>0</td>
</tr>
</tbody>
</table>

Using risk scenario in Table 2, estimated probabilities of hazards on each
alternative are presented in Table 3.

**Table 3. Evaluation of probabilities for each of the alternatives**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Probability of success</th>
<th>Probability of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1 ≤ p ≤ 0.3</td>
<td>0.3 ≤ p ≤ 0.6</td>
</tr>
<tr>
<td>2</td>
<td>0 ≤ p ≤ 0.1</td>
<td>0.6 ≤ p ≤ 1</td>
</tr>
<tr>
<td>3</td>
<td>0.6 ≤ p ≤ 1</td>
<td>0 ≤ p ≤ 0.1</td>
</tr>
<tr>
<td>4</td>
<td>0.1 ≤ p ≤ 0.3</td>
<td>0.3 ≤ p ≤ 0.6</td>
</tr>
</tbody>
</table>

Using the inaccurate probabilities method, the probability values of Table 4 are
obtained.

**Table 4. Alternative probabilities**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Probability of success</th>
<th>Probability of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.35</td>
<td>0.65</td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td>0.95</td>
</tr>
<tr>
<td>3</td>
<td>0.95</td>
<td>0.05</td>
</tr>
<tr>
<td>4</td>
<td>0.35</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Then,

\[ r(s, a) = c_1 \alpha_1 + c_2 \alpha_2 + c_3 \alpha_3 = \sum_{s' \in S} p(s'|s, a) r(s, a, s') \]  

(4)
Considering the following criteria weights of 0.50 for the cost \( C \), 0.50 for the time \( D \) and 0 for the quality \( Q \), we can determine the utility of each alternative in case of failure or success (Table 5).

Table 5. Alternative rewards.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Reward on failure (CFA francs)</th>
<th>Reward on success (CFA francs)</th>
<th>Gain planned (CFA francs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-7 500</td>
<td>0</td>
<td>150 000</td>
</tr>
<tr>
<td>2</td>
<td>-7 500</td>
<td>0</td>
<td>300 000</td>
</tr>
<tr>
<td>3</td>
<td>-7 500</td>
<td>0</td>
<td>95 000</td>
</tr>
<tr>
<td>4</td>
<td>-7 500</td>
<td>0</td>
<td>200 000</td>
</tr>
</tbody>
</table>

The decision tree (Figure 4) allows us to better visualise the challenges of each choice.

2.2. Results

The function value for each alternative is given by equation 5.

\[
V_0^* = r_0(s, \alpha) + \sum_{s' \in S} p_\alpha(s'|S)V_{s'}^*(s')
\]  

(5)
Where:

- \( i \) is the number of the alternatives;
- \( r_0(s, a) \) is the immediate reward perceived by the choice of alternative (equation 4);
- \( \sum_{s' \in S} p_n(s'|S)V'_i(s') \) is the random reward perceived by the choice of alternative \( i \);

The random reward is calculated taking into account all the risks and additional costs that may arise due to the choice of this alternative. The calculation results of the expected reward for each alternative are given in Table 6 and shown graphically in Figure 5.

**Table 6. Expected value of each alternative**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>The reward on failure</th>
<th>Initial gain planned</th>
<th>Probability of failure</th>
<th>Probability of success</th>
<th>Random reward on failure</th>
<th>Expected value (CFA francs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>-7500</td>
<td>150000</td>
<td>0.65</td>
<td>0.35</td>
<td>-4875</td>
<td>47625</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>-7500</td>
<td>300000</td>
<td>0.95</td>
<td>0.05</td>
<td>-7125</td>
<td>7875</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>-7500</td>
<td>95000</td>
<td>0.05</td>
<td>0.95</td>
<td>-375</td>
<td>89875</td>
</tr>
<tr>
<td>Alternative 4</td>
<td>-7500</td>
<td>200000</td>
<td>0.65</td>
<td>0.35</td>
<td>-4875</td>
<td>65125</td>
</tr>
</tbody>
</table>

**Figure 5.** Expected value in CFA francs

We note that although the alternative 3 has the lowest initial gain, it is characterised by the highest expected value. In contrast, alternative 2 has the highest initial gain, but is characterised by the lowest expected value. Thus, alternative 3 is the best option for a decision-maker to pursue to perform a construction work. The results show that hazards can have the same impact on the execution of the task, but decisions can reduce the likelihood of occurrence and therefore the risk of success or failure. This demonstrates the importance of the choices made in reducing hazards.
3. Discussions

Construction projects are often exposed to many vulnerable conditions leading to risks and uncertainties that generate decision problems. In this study interactions between different vulnerabilities on a construction site have been identified and categorized. For example, a site manager can be responsible for the provision of construction materials. This involves choosing suppliers or materials, and the stock management. A project manager can be in charge of equipment, manpower and method. The choice of equipment involves interaction between the needs, access, storage facility and cost. The selection of man-power involves the interaction between the needs and the training capacity. The choice of execution method involves interaction between tasks scheduling, availability of man-power or equipment, and weather conditions. A task is an operation that consumes resources including materials, equipment, labour and technical implementation. It is also characterized by dependent factors such as the task execution time \( D \), the task cost \( C \), and quality \( Q \). The MDP model was applied to the methods control related to the structural works with 4 alternatives (BGM; MGM; BCF; MCF) and risk scenario presented in section 2.1 (see Table 2). The result revealed alternative 3 (BCF) to be the best option for the project manager to pursue as it offers the highest expected outcome. Thus, choosing experienced suppliers is very important to reduce most site uncertainties related to structural works (time, cost, quality).

Conclusion

The construction site is a highly uncertain environment. Methods of project management commonly used by companies in developing countries are essentially planning schedules. Often, the methods are based on the assumption that complete knowledge of the project is known. The study conducted was designed to improve the management of construction projects through the rationalization of decision making by providing a Markov decision model to reduce the impact of uncertainty on cost, quality and time. The model provides an opportunity to identify the increase of additional costs associated with bad decisions, and the need for the site manager to fully explore the range of possible actions.

Although the model has been used for projects in Cameroon, it can be applied to projects in other developing countries with similar conditions. The shortcomings of the model may arise from assumptions made in the case of decentralization of decisions (outsourcing). Also, learning and perception on construction sites are mostly based on visual observations that can gradually improve. In this case, practices such as information management, quality control, skills management and internal audit will reduce errors of perception. We intend to continue this study by developing a database of common hazards encountered on construction sites and the evaluation of their occurrences as part of future study.
References


