A FAHP-BASED TECHNOLOGY SELECTION AND SPECIFICATION METHODOLOGY

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Abstract: Selection of technology in IT projects is recognized as a multi-criteria decision-making (MDCM) problem because it is important to incorporate multiple opinions from people and consider the interdependence among criteria (Lee and Kim, 2000). Various techniques were proposed to address the technology selection problems and some of them, such as analytic hierarchy process (AHP) (e.g. Bard, 1986), were proved effective in literatures. However, technology selection problem in a system development project can be viewed as a system design activity and there is lack of literatures view technology selection from system design perspective and integrate it with other system design activity. The research argues that AHP can be applied to generate technology specification and other useful information for system design purpose, in additions of technology selection. A high-level system design framework and the FAHP-based technology selection and specification (TSS) methodology are presented in this paper.

1 INTRODUCTION

Assessment and selection of technology in IT projects are required when more than one alternative are available and commit to a right technology can lead to optimal benefits to the business. Literatures (e.g. Chou et al., 2004) suggested that the technology selection can be viewed as a MDCM problem. It is because it involves activities that intakes multiple opinions from different parties and considers the interdependence among criteria (Lee and Kim, 2000). Analytic hierarchy process (AHP) has been studied extensively and been used in almost all the applications related with MCDM in the last 20 years (Ho, 2007). Literatures (e.g. Bard, 1986; Nelson and Kastenberg, 1986) indicate that AHP is an effective technique in the field of technology selection.

Technology assessment and selection happens in two stages of an IT project: project justification (Gunasekaran et al., 2006) and system design. The former activity may influence the later process by providing partial technology selection decisions to system designer in order to bind the developing system to certain technology strategically.

From a system development perspective, technologies that compose the developing system must be well-defined in the system design process. However, there is lack of literature associates technology selection with system design activity. Also, the research proposes that the characteristics of AHP provide opportunities for system designer to collect useful information from people for purposes not limited to technology assessment.

The research proposes a generic high-level system design framework and an FAHP-based technology selection and specification (TSS) methodology as a member of the framework.

2 A HIGH-LEVEL SYSTEM DESIGN (HLSD) FRAMEWORK

According to Sommerville (2002), system design generally encompasses six activities include architecture design, abstract specification, interface

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design, component design, data structure design and algorithm design. Each of the activity takes design product input from previous activity and generate design product for the next activity (see figure 1).

In particular, the architecture design activity aims to identify sub-systems and relationships of the system while the abstract specification aims to specify the sub-system. These two activities aim to describe a complete picture of system with system architecture and specification of the architectural components. On the other hand, the other four activities specify the details of the architectural components. Therefore, these six activities can be separated into two groups according to the level of detail they concern, namely ***high-level design*** activities and ***detailed design*** activities.

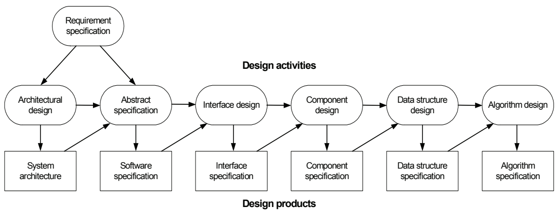

Figure 1: A general model of the system design process (source: Sommerville, 2002).

According to above, there are two general high-level design activities and they aim to produce the system architecture and system specification for the use of detailed design. Technology may be decided strategically before the high-level design. Despite the technology decisions made in project justification before system design, the need for technologies must be identified after the relevant details of the related architectural components are defined. This indicates that the technology selection is a part of the abstract specification activity. In fact, the activity aims to generate a system specification which includes the technology definitions.

The research proposes a high-level system design (HLSD) framework based on Sommerville's generic model and results from case studies. Based on case studies, eleven functional areas of abstract specification including technology selection and specification are identified. The framework covers the scope of the two activities mentioned above and proposes that the second activity is composed by the eleven identified functional areas. The eleven functional areas are divided into four groups, indicated by four different colours, according to the subject they concern. The framework aims to identify the role of technology selection within a general system design process. Figure 2 illustrates the proposed high-level system design (HLSD) framework.

A FAHP-based TSS methodology is proposed in section 4 that supports technology selection and technology specification indicated by figure 2. The function of the proposed methodology is to provide a mean for decision-makers to assess technologies and then select technologies among alternatives. Furthermore, it utilizes the AHP process to collect useful information from people and thereby generate technology specification of the developing system which serves as the part of the content of system specification.

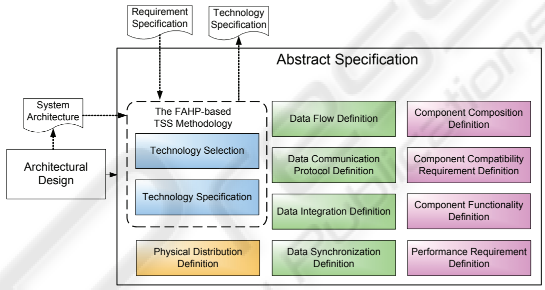

Figure 2: The proposed HLSD framework.

3 FUZZY-AHP (FAHP)

3.1 Introduction to FAHP

AHP was developed by Saaty in 1971 (Saaty, 1980) and is recognized as an effective technique for handling unstructured or semi-structured decision-making problem with involvements of multiple persons and multiple criteria inputs simultaneously (Durán and Aguilo, 2007; Saaty and Kearns, 1985). It has been proved to be effective tool for decision supporting in MCDM problems such as ranking, selection, evaluation, optimization, and prediction (Lee et al., 2001; Ho, 2007). In particular, AHP has been extensively applied to various technology selection problems and is proved to be an effective approach (e.g. Bard, 1986; Lai et al., 1999).

According to Saaty (1980) and other literatures (e.g. Liu et al., 2007; Lee et al., 2006; Chang, 1996), the conventional AHP encompasses two phases: decomposition and synthesis. The first phase is to decompose the complexity of problem by building a hierarchy model in order to discover and structure the relations. The second phase is to obtain useful results with the hierarchy model through pairwise comparisons and other techniques.

However, AHP has weakness in treating fuzziness and vagueness data which commonly exist in many decision-making problems (Levary and Wan, 1998; Ribeiro, 1996). Integrate the fuzzy set theory to the pairwise comparison of the AHP is believed an effective solution (Karsak and Kuzgunkaya, 2002; Mon et al., 1994). The integration of the fuzzy set theory and the conventional AHP is named fuzzy-AHP (FAHP) which was first introduced by Van Laarhoven and Pedrycz (1983).

The FAHP approaches presented by literatures (e.g. Lee et al., 2006; Liu et al., 2007; Chang, 1996) are variable in steps and use of techniques. According to literatures (Lee et al., 2006; Liu et al., 2007; Sadiqa and Husain, 2005; Zeng et al., 2007; Durán and Aguilo, 2007), FAHP has modified the conventional AHP with the following steps generally:

- Fuzzification: judgments are transformed into fuzzy values and pairwise comparisons are based on fuzzy judgment matrices.
- Synthesis: instead of dealing with crisp judgment values conventionally using techniques such as eigenvalue and eigenvector, FAHP approach handles synthesis in a fuzzy environment. Methods such as fuzzy extent analysis (Chang, 1992, 1996) were proposed by literatures.
- Defuzzification: in order to obtain an overall ranking of alternatives, the score of alternatives in fuzzy number must either be transformed into crisp number or be compared.

3.2 FAHP as a Technology Selection and Specification Approach

FAHP is adopted in the proposed TSS methodology not only for technology selection purpose but also for generation of information. FAHP is adopted for the reason of its characteristics and the advantages it brings:

- AHP is "*excellent for clarifying a problem and displaying the decision process*" (Nelson and Kastenberg, 1986). Useful information such as end users' and decision makers' concerns and preferences, performance measurement of alternatives, and reasons of selection result can be identified through the AHP process. In the proposed methodology, AHP process contributes in the production of technologies specification.
- AHP is a powerful tool for communication (Roper-Lowe and Sharp, 1990). Outcome from AHP is a conclusion of selected participants' judgments. This meets the need in an IT project that people from different parties can be involved in selection of technology. This also shares the responsibility among different people as well as have useful data input from appropriate people.
- Use of FAHP instead of conventional AHP means a significant benefit in a technology selection problem since failed to deal with the data fuzziness can lead to inaccurate performance measurement of alternatives.

4 THE FAHP-BASED TECHNOLOGY SELECTION AND SPECIFICATION (TSS) METHODOLOGY

4.1 Objectives

The proposed FAHP-based TSS methodology aims to facilitate the high-level design process mainly by 1) provides a mean for decision makers to assess alternatives and make decision on selection of technologies; 2) specify technologies and generate respective technology specifications.

4.2 Multi-level Solution Structuring

As a matter of previous literatures, technology is to be evaluated and decided separately from other parts of the system. The proposed methodology considers technology selection as a part of system design activity which aims to achieve a technology solution instead of only part of it.

To do that, the selection and specification needs of the developing system must be identified and structured into multiple hierarchical levels. Terminologically, the top level is the technology ***solution*** that includes ***solution components*** at lower levels. A solution component means a particular architectural component which requires the technology selection and specification process. For instance, design of an enterprise system requires selection and specification of a database management system which can be viewed as a solution component. A solution means a set of solution components indicated by system architecture.

The proposed methodology aims to evaluate alternatives of different solution components efficiently and thereby propose the best-performed solution considering compatibility issues.

4.3 The Six Phases

The proposed methodology is illustrated by figure 5. It includes six phases: Preparation, Decomposition, Solution Component Decomposition, Solution Component Assessment, Solution Assessment, and Conclusions. Each phase contains one or more steps and each step is composed by one or more process. Process may require external data input such as the requirement specification document and survey results.

The proposed methodology begins with the ***Preparation*** phase in which a project team must be constituted (*process 1.1.1*) and the team will act as an important source of data in the later stages.

The second and the third phases are ***Solution Decomposition*** and ***Solution Component Decomposition*** respectively. The term "decomposition" was adapted from the first of the two basic phases of conventional AHP according to Saaty (1980). Decomposition is a process that decomposes the complexity of problem by building a hierarchy model in order to discover and structure the relations (Saaty, 1980).

In the second phase, the goal (*process 2.1.1*) and objectives (*process 2.1.2*), solution components (*process 2.2.1*) and the alternatives (*process 2.2.2*) of them are identified and arranged into a solution-level hierarchical model. Example of the goal can be "*Evaluate and specify the most suitable technology solution* ". *Process 2.1.2* is a generalization process that translates the requirements into objectives for technology. The objectives must be created based on requirement specification in order to ensure the selection and specification results are responsible to it. The solution components can be defined with system architecture created previously in system design process.

As the outcome of the phase, the hierarchical model is based on a well-defined fundamental-objective hierarchy (*process 2.1.3*) that graphically illustrates the relations between the hierarchy elements (see figure 3 for example). In particular, compatibilities of alternatives of each solution component to alternatives of each other solution component are considered. The alternatives that are considered completely incompatible or poorly compatible to alternatives of other solution component should be eliminated (*process 2.2.3*).

In the third phase, solution-component-level hierarchy models are created. While the solution-level hierarchy model reflects the solution-level elements, a solution-component-level hierarchy model is defined with a solution components perspective in regard to the solution-level goal and objectives.

Each solution component will have a hierarchy model created as the output of the third phase. The third phase is composed by two steps (*step 3.1 and 3.2*) and they are in iteration where each round will create a solution-component-level hierarchy model for one solution component. A solution-component-level hierarchy model is created by define the means to the solution-level objectives by a particular solution component (*process 3.1.1*) and thereby to build the respective means-objective network for the solution component (*process 3.1.3*). As the means-to-objectives of different solution component can be different, some solution-level objectives may be found irrelevant to certain solution component and they must be eliminated from the solution-component-level hierarchy (*process 3.1.2*). On the other side, goal for the hierarchy must be defined according to the solution-level goal (*process 3.2.1*). With the goal and objective structured, the fundamental-objective hierarchy can be defined

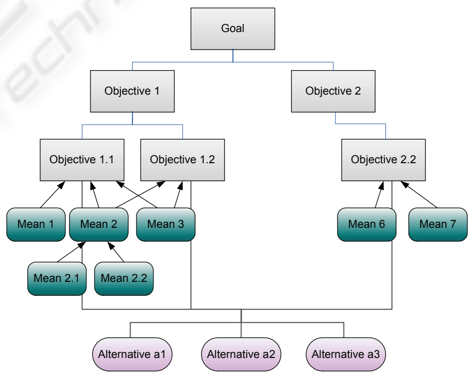

Figure 3: An illustrative example of a solution-level hierarchy model.

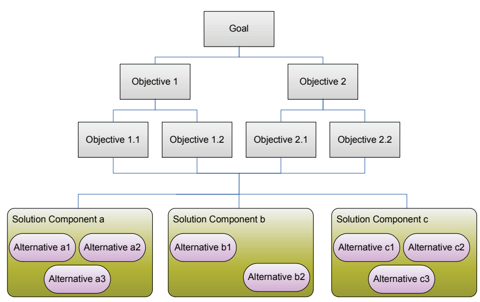

Figure 4: An illustrative example of a solution-component-level AHP hierarchy model.

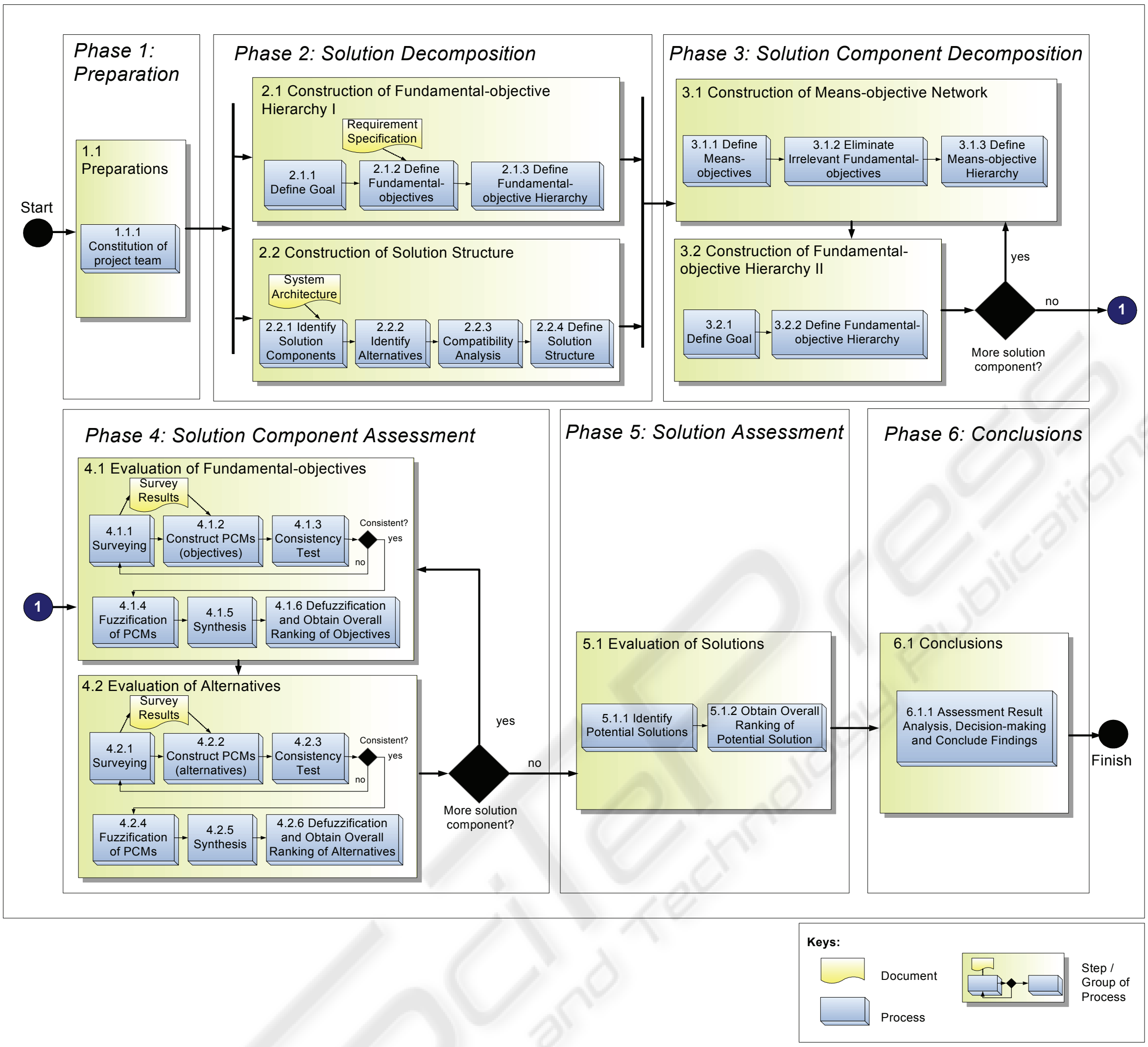

Figure 5: The proposed FAHP-based technology specification (TSS) methodology.

(*process 3.2.2*). A means-objective network and a fundamental-objective hierarchy together form a solution-component-level hierarchy model (see figure 4 for example).

Following the decomposition phases, the created hierarchy models will be used in the fourth phase ***Solution Component Assessment***: It is a FAHP-based process for assessment of each solution component. It consists of two steps (*step 4.1 and 4.2*) and they are in iteration where each round will have created assessment result for one solution component. General FAHP steps are proposed in this phase: surveying (*process 4.1.1 and 4.2.1*), building of pairwise matrices (*process 4.1.2 and 4.2.2*), consistency test (*process4.1.3 and 4.2.3*), fuzzification (*process 4.1.4 and 4.2.4*), defuzzification and obtain overall ranking as the assessment result (*process 4.1.6 and 4.2.6*).

The key differences of the use of FAHP in the proposed methodology from other FAHP/AHP-based approaches in literatures can be summarized as below:

- The proposed methodology is not for project justification purpose but for the system design benefit. Instead of involving people from different background, *Step 4.1* of the proposed methodology requires the involvement of experts to the fields of relevant technology. It helps to improve the data quality and the accuracy of assessment results.
- Assessment of alternatives in *step 4.2* requires judgers to make judgment based on the means-to-objectives and the objectives are the

generalization results of requirement specification. Therefore, the means-objective network acts as a linkage between the requirement specification and participants' judgments. This ensures the assessment results be responsible to requirement definitions.

- Judgers must provide evidence for the judgment based on the means-to-objectives. The evidence can be qualitative knowledge relate to the alternatives or quantitative measurement of their capabilities. These information explain how and how well a technology alternative satisfies the objectives. In additions, the information can be used for generate specification information about the assessed alternatives (*process 6.1.1*).

Alternatives of each solution component are ranked at the end of assessment (*process 4.2.6*). The rankings of solution component alternatives can be used to derive a score with crisp value through defuzzification methods, for example. The scores are useful for the assessment of the potential solutions in the fifth phase ***Solution Assessment***. With the result from the compatibility analysis (*process 2.2.3*), the potential solutions to be assessed must first be defined (*process 5.1.1*) and thereby to be assessed (*process 5.1.2*). The assessment aims to rank the potential solutions by assign an overall score to each of them. An overall score is obtained through calculation with the scores of included solution component alternatives. The calculation should consider the relative importance of solution component and other necessary criteria. The final scores reflect how relatively well the solutions satisfy the solution-level objectives for the solution-level goal in regard to the requirement specification.

Finally, the sixth phase ***Conclusions*** provides a space for decision makers to make use of the information generated through the previous phases. The best performed solution(s) suggested by *phase 5* will be proposed to decision makers and thereby decision makers may make decision on technology selection. On the other hand, the specification information of technologies can be identified qualitatively and/or quantitatively in *phase 4*. The *process 6.1.1* concludes these findings and documents relevant information to form the technology specification for the detail design and for other project management purpose. Furthermore, other useful information such as relative importance weight of objectives obtained in *step 4.1*, ranking of alternatives obtained in *step 4.2*, and score of potential solutions in *step 5.1* can be documented for various project management purposes as well.

5 CASE STUDY

5.1 Background

This section outlines the use of the key steps of the application of the proposed TSS methodology to a transportation management system development project.

ContainerPort (www.containerport.co.uk) is a commercial project conducted by the Aimes Centre (www.aimes.net), the University of Liverpool. The project has developed an UK-based transportation management system with GPS (Global Positioning System), Oracle database, Microsoft .net Platform, and Web portal technologies.

Technology selection and specification were important in the system design stage of the system development process. The proposed TSS methodology was applied to the case for testing and demonstration purposes.

5.2 Demonstration of the TSS Methodology

This section briefly outlines the key activities of the six phases of the TSS methodology with the case study.

In the first phase, a project team was formed with project manager and technology experts from the IT consultant (the Aimes Centre), personnel from management level of clients and end user.

In the second phase, solution components, alternatives of them, and solution-level fundamental-objective hierarchy were defined with goal "*select and specify the best technology solution*". Table 1 shows the 4 identified solution components and their alternatives.

Table 1: Solution component and alternatives.

Solution Component	Alternatives
Database management system	Oracle database, SQL database
Vehicle tracking technology	Long-range RFID (Radio Frequency Identification), short-range RFID, GPS system
Software platform	Microsoft .Net Platform, Java-based platform
Presentation	GUI , Web page
Network Connection	Web standards, private network standards

Therefore, the third phase had the four AHP hierarchy models created with means-objective network and the fundamental-objective hierarchy included. Each of the models was created for assessment of one of the solution components in the next phase.

The FAHP processing in the fourth phase has suggested the best-performed alternative of the solution components as shown in table 2.

Table 2: Solution component assessment results.

Solution Component	Best Performed Alternative
Database management system	Oracle database
Vehicle tracking technology	GPS system
Software platform	Microsoft .Net Platform
Presentation	GUI
Network Connection	Web standards

Through the assessment process, information of judgment and reason for judgment were collected from experts. The data explain the reason for assessment result as well as providing specification data of the technologies. For instance, GPS was believed more preferable for the lower implementation cost as well as its satisfying capabilities. Before researched above opinion, capability and implementation cost of GPS and other alternatives were given, evaluated and compared. The information was documented for technology specification purpose.

Although GUI (Graphical User Interface) was recognized as the best-performed presentation technology for the capability, the fifth phase had proposed the best-performed solution without it. The main reason was that GUI was recognized relatively less compatible than that of web portal in the fifth phase: it requires installation of extra application on user's computer, local security settings may disallow database connection, and GUI-based application is usually software platform dependent. Accessing Web portal through Web browser will not meet above problems and thereby will work better with other solution components. The proposed solution includes Oracle database, GPS system, .Net Platform, Web portal, and web standard network.

The best-performed solution above is currently applied by the live system. As there has no issue indicates any need in change of technology after the system has gone live for approximately a year, I can conclude that the proposed methodology provides satisfying selection result to the goal.

6 CONCLUSIONS

A HLSD framework was proposed to indicate the role of technology selection process within a generic system design process. It suggests that the technology specification and specification can be a separate activity apart from other functional areas of abstract specification.

A FAHP-based TSS approach was proposed to support technology selection and specification activities of the HLSD framework. As a part of the framework, it takes input from the previous system design step and aims to generate specification information for later system design activities. By taking the advantages of AHP (see section 3.2), the proposed methodology attempts to generate useful information, such as technology specifications, for system design and project management purposes. The proposed methodology applies the means-objective network technique to strengthen the linkages between requirement specification and decision-makers' judgments in order to ensure that both technology selection and specification results are responsible to the requirement definitions. The proposed methodology also introduced the multiple-hierarchical-level solution structure technique to address the system design needs.

Beside the general advantages of FAHP that was mentioned in section 3.2, some advantages of the proposed FAHP-based TSS methodology are outlined below.

- Complete picture of technology solution is considered by the proposed methodology with compatibility issues between solution components.
- Instead of assess all of the potential solution using pairwise comparison according to conventional AHP approach, the proposed methodology divides the assessment of solution into two parts – *phase 4* and *phase 5*. This greatly reduces the number of comparison judgment necessarily to be made and thereby has improved the efficiency. It implies reduction in risk of creating inconsistent datasets.
- As the proposed HLSD framework is developed based on a general design process model (see section 2), it's highly adaptable by various software process model such as waterfall model.

Nevertheless, there are several identified limitations of the proposed TSS methodology that indicates space of improvement in the future. For example, although the TSS methodology considers the compatibility of solution component alternatives in assessment of potential solutions, it can be more specific in handling different levels of compatibility since it may influence the ranking of potential solutions effectively.

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