A PROPOSED MODEL FOR IMPLEMENTING RAMS IN THE DESIGN PROCESS IN CONSTRUCTION

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Abstract
In construction in the Netherlands, there is a growing trend of outsourcing of public construction activities to the private sector through the use of integrated contracts. There is also an increasing emphasis on the importance of the application of the concept of RAMS, an acronym for (Reliability, Availability, Maintainability and Safety) and the use of Life Cycle Costing (LCC) in the design process of infrastructural projects to improve the performance of the designed systems and optimize the project cost. In some cases, the parties responsible for the design would be required to provide evidence of the application of RAMS in their design.

A preliminary literature study and evidence from practice have shown that the knowledge and application of RAMS in infrastructural designs are in their infancy compared with other industrial sectors and many designers in construction do not have the knowledge and experience in how to apply it.

This research describes a proposed model for the integration of RAMS and LCC into the design process in construction based on the knowledge acquired from other industries. It involves decomposing the RAMS requirement into design requirements and guidelines to simplify its application by the designers. The model has been validated for its practicality and usefulness during a workshop by experienced designers.

Keywords: Construction, Design process, RAMS, Life Cycle Costing, Model

INTRODUCTION

The Dutch construction industry is changing and the main evidence of this change that is relevant to the subject of this research is the increase in the use of integrated contracts and Life Cycle Management. The increase in the use of integrated contract means that contractors have to take new roles and to carry out activities that are traditionally carried out by other parties. It also means that their involvement in the project covers more phases than just construction. For example in the cases of contracts that involve maintenance, such involvement will extend long after the projects are finished. The implementation of Life Cycle Management is also becoming more important and as part of the requirements of the new types of contracts. Its use implies a constant focus on all phases of the Life Cycle of a
system with the objective of optimising its costs. The application of Life Cycle Management or, specifically Life Cycle Costing (LCC), within integrated contracts that involves maintenance obligation means the need to investigate many design alternatives to find the one which gives the best balance between cost, performance and the maintenance strategy. In this context the application of LCC will benefit the construction company, involved in an integrated contract with a long maintenance period, by considering alternatives and then making design decisions aiming at optimising the total life cycle cost of the project. One of the methods that can be used to do this is called RAMS, an acronym for Reliability, Availability, Maintainability and Safety. According to CENELIC (1999) RAMS is defined as ‘a qualitative and quantitative indicator of the degree that the system, or the subsystems and components comprising that system, can be relied upon to function as specified and to be both available and safe’. The method is widely used in design in other industries such as Chemical or Nuclear industries but is fairly new and unknown for designers in the construction industry. The concept behind the application of RAMS is that the cost in diagnosis and repair of a fault early in the production stage could be one tenth of the cost needed to rectify it in a later stage of production. If however the failure is related to design fault, the cost of redesign, documentation may be much higher than that and could run into hundred times the original estimated cost.

Figure 1 shows an example of a study based on the application of RAMS in a major construction project in the Netherlands. The study relates to the rail project ‘HSL-Zuid’ which is delivered on the basis of a DBFM (Design, Build, Finance and Maintain) contract. The contractor ‘Infraspeed’ (a consortium of a number of companies) was required to design, build and finance a 100 kilometre long rail track and to maintain it for a period of 25 years. During the 25-year maintenance period ‘Infraspeed’ has to ensure availability of the ‘HSL-Zuid’ for at least 99% of the time during operational hours, see Infraspeed (2004). The contract stipulates that failure to do that will result in reduced payments. The figure shows how various alternative designs of the rail track are presented on the basis of LCC concept and how for example an alternative with a higher construction cost can be more economical in the long run in terms of its total life cost.

![Figure 1: A chart of the composition of the Life Cycle Cost for four different track-types of the HSL-Zuid, (Zoeteman, 2001). (the costs in the chart are fictive because of confidentiality)](image-url)
The example shown in Figure 1 is not representative of the common practice in construction in the Netherlands. Most designers are not familiar with RAMS method or the application of LCC during design. However there seems to be an agreement in the construction industry for the need to integrate the RAMS analysis & LCC in the design process.

To improve the integration of RAMS analysis in the design process in construction, a number of interviews and a literature study were conducted to understand how this is done in other industries. The construction industry was then compared with those industries that have long experience in the use of RAMS analysis. The results of the comparison were subsequently used to develop two proposed models for the application of RAMS in design process in construction. This paper describes the proposed models for the application of RAMS in the design processes of infrastructural projects. The applicability and usefulness of the proposed models were validated by a number of experienced design managers through a workshop during which the models were discussed and feedback was provided.

APPLICATION OF RAMS IN OTHER INDUSTRIES

RAMS is a new concept for many designers in the construction industry. When designers were asked about their experiences with RAMS analysis, most indicated that they didn’t know what RAMS is. Other industries such as Defence, Nuclear, Chemical and the Aeronautic industry, have decades of experience with the use of RAMS analysis in their design process. An important reason why RAMS is widely applied in other industries but not in the construction industry is related to its association with Systems Engineering. The Systems Engineering design method is a standard method in the design processes of the other industries. RAMS analysis is part of Systems Engineering method used to provide indication on the performance of the designed systems. Systems Engineering has only been introduced relatively recently in the construction industry, hence the applications of RAMS procedure within the industry’s design practices remains slow and limited.

To benefit from the long experiences of other industries in the applications of RAMS, a comparison was conducted between them and the construction industry; see Guedes et al (2003). The comparison was carried out based on literature review as well as a number of interviews conducted with experts from the industries considered. The result of the comparison provided an overview of the way other industries use RAMS analysis in their design process with the way it is currently applied in the construction industry. The objective was to learn from practices in the other industries and to make the necessary adjustments required for improving the RAMS analysis procedure in the construction design process. The comparison was made on the basis of six aspects:

- Sector specific experience with the use of RAMS
- Utilisation of Life Cycle Management
- Criteria as to the extent RAMS should be used
- Application of RAMS methods
- Use of RAMS from an organisational viewpoint
- Views on RAMS

Summary of the results of the comparison is presented in Table 1. It can be seen from the table that in addition to the construction industry (represented by the experience of a major Dutch company), four other industries have been analysed.
Table 1: Summary of the results of the comparison between the use of RAMS in the construction industry and in other industries

The comparison shown in Table 1 above shows that the knowledge and application of RAMS in infrastructural designs are in their infancy compared with other industrial sectors and hence many designers in construction do not have the knowledge and experience in how to apply it. Based on the comparison results, discussion and recommendations to improve the application of RAMS in construction are made under the various aspects as follows:

- **Sector specific experience with the use of RAMS**
  The comparison shown in Table 1 indicates that the application of RAMS analysis as part of the design process in construction is quite novice. One reason for that is that there is the feeling, as expressed by some experts during the interviews, that the need for RAMS in construction is not as large as it is in other industries. In Aeronautic industry for example airplanes are designed with the need for high ‘availability’ in mind. To be competitive the ‘price per seat’ can be reduced by making the planes fly as often as possible. This means that planes should be very reliable and maintainable.
The construction industry doesn’t compete ‘yet’ on basis of the availability of the designed systems. Another reason is related to the type of production in the construction industry. The industry is characterized by its ‘one of a kind’ products which means having less advantage compared with mass production type of systems in other industries whereby products can be continually tested.

- **Utilization of Life Cycle Management**
  The literature review and interviews carried out in this work have shown that construction can learn from the other industries in terms of the application of LCC. The consideration of and comparison between alternative design solutions are not standard procedures during the conceptual design phase in construction. Based on the experience of other industries the first step for possible improvement in the application of LCC in construction is to integrate the development of conceptual design alternatives as part of the RAMS procedure. In the Defence and Aeronautic industries for example the use of brainstorming sessions over alternative conceptual designs is a standard procedure. The development of alternative conceptual design in construction is usually carried out by the client and LCC is mainly used for the evaluation of these alternatives and normally only for the phases that are relevant for the contract. The evaluation of Design & Construct contracts takes place on the basis of the amount of investment that includes design and construction costs. In other sectors such as Defence for example the application of LCC continues even after the commissioning of the project and through the operational phase. The performance of the system and subsystems are monitored for possible adjustment, improvement and for the optimisation of the LCC, Noortwijk and Frangopol (2004). Information is also collected in a structured manner for use in future projects. During the interviews experts pointed out two main reasons for the limitation in the application of LCC in construction. The first is that the span of the life cycle the clients are usually interested in is not long. For example even in DBFM contracts, the maintenance period specified is usually not more than 25 years. This is a short period in comparison to the life span of most Civil Engineering Systems. The other reason for the limited use of LCC is that in many contracts, clients’ requirements are usually too pre-determined to provide the designers the freedom to consider alternatives to choose from and to optimise LCC of the project.

- **Criteria as to what extent RAMS should be used**
  To answer the questions as to when and to what extent RAMS should be used, a number of RAMS specialists and designers indicated that the contract type is one of the most important criteria to consider for this purpose. In the case of a traditional type of contracts in which design is already being made and the specifications are determined there is little point or benefit in implementing RAMS analysis. RAMS procedure is either used in contracts in which it is required to do so or in integrated contracts that include maintenance responsibilities.

In addition to contract type, there are other criteria which were considered to be important for deciding on whether RAMS is to be used or not. These are:

- *Complexity of the systems to be designed*: The benefits of using RAMS are more obvious in the case of complex systems than in simple systems. The RAMS analysis should provide a better understanding of the system and detailed calculations of LCC.
- **Design freedom**: The provision of detailed requirements by the client will affect the designer’s freedom to be creative and hence will limit the usefulness of applying RAMS analysis in the process.

- **Contract requirements and the levels of detail**: The extent of details of the system requirements provided by the client affects the RAMS implementation in two ways. On one hand too many details will restrict the designer’s freedom and hence will make RAMS less effective. On the other hand detailed requirements can also mean more demand of designers to work out the detailed solution to the problem. This often means that the calculation for design solution will be based on quantitative data. For example the contract may specify that the required system’s availability to be 99% of the time in a certain period or it may also specify that life cycle cost needs to be optimised. In this case RAMS will become more relevant to improve the availability of the system to achieve the targeted requirement or to show how the LCC of the system can be optimised.

- **Project cost**: This criterion determines the extent to which RAMS analysis can be applied. Large projects have relatively more money available for them than small project and hence justify spending the time and cost on implementing RAMS analysis.

**Applications of RAMS techniques**

Because of the importance of the criterion ‘contract type’ in the decision on whether and how to apply RAMS analysis, it has been suggested in this work to develop & use two separate RAMS procedures, one for the contracts that don’t include maintenance (D&C contracts in their many forms) and one for contracts with maintenance (mainly DBFM. It is important at the tender phase to decide on the inclusion of RAMS & LCC procedures as part of the design process as it is the case in other industries. The first step of the tender phase is to make RAMS requirement clear. In case of ambiguity in the client’s requirements, the contractor undertaking the design task should make sure to ask the client for clarity on the specified functional requirements; how they can be measured as well as the time frame within which they are required to be achieved. For the contractor the applications of RAMS and LCC in the development of alternative conceptual designs will be focused only on the phases he/she is responsible for based on the clauses of the contract. Ideally however the most optimal results could be achieved when all phases of the project, including demolition, are considered.

As far as techniques used by the RAMS analysis, experiences from other industries show that the most commonly used techniques are Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Failure Mode and Effect Criticality Analysis (FMECA) and Safety Analysis, see Venkatasubramanian et al (2001). All of these techniques are characterized as being straightforward and therefore can be easily understood and applied by designers. The FME(C)A is recommended to be used for preliminary design phase since it is object-related technique and the design in this phase is more detailed than in the conceptual design phase. FMECA can however be used in the conceptual design phase for identifying possible risks.

The literature study and interviews have indicated that RAMS is increasingly being implemented in greater detail in the design process. This usually requires more detailed data. In the conceptual design phase for example data based on experience from other projects could be used since design is still in its very early stages. However
the need for detailed data will grow as the design develops because the data will be used to calculate, for example, the availability or the reliability of the systems and subsystems. In deciding on the choice of certain components of the system for example, detailed data from suppliers are required.

- **The use of RAMS from an organizational viewpoint**
  An important lesson to be learned from other industries regarding the implementation of RAMS is that in other industries the responsibility for RAMS is usually clear and integrated as part of the organisational structure. In the Aeronautic industry for example the RAMS responsibility is normally assigned to the Chief Engineer and in some other cases to the so-called RAMS Engineer. In the case of the construction company investigated in this research, the responsibility for RAMS is normally assigned to the design manager. However in almost all previous cases within the construction company which was under study, the design manager had shifted this responsibility to the RAMS Engineer either because the design manager lacked the experience in the application of RAMS or because he put less priority on its importance. The major problem with that is that often the RAMS Engineer is added to the project design team through the functional department where he usually works and hence has no direct authority to manage the process or take decisions. One of the solution suggested to overcome this problem is to integrate the responsibility of RAMS within the line organisational structure of the company. For large projects this can be done by assigning the responsibility to the so-called System Integrator who will be subordinate to the design manager. The System Integrator will be responsible for the overall view of the RAMS application and its integration into the design process. For small projects the responsibility for RAMS would remain with the design manager.

- **Views on RAMS**
  The results of the interview have shown that the views of people who have long experience with the implementation of RAMS were very positive about the analysis. In the Aeronautic & Nuclear sectors there is a long experience in the use of RAMS and the people who are involved find it as part of their normal work procedures. This is still not the case in construction and most designers are sceptic about the use of the analysis either because they don’t know how to apply it or because they don’t see its benefits. There is also the problem of not knowing who should be responsible for implementing it within the design organisation.

**THE PROPOSED MODEL**

As a result of the literature study, interviews with experts and the comparison between different industrial sectors, two models for integration of RAMS activities into the construction design process have been developed. The two models are for two types of contracts, one is for the application of RAMS in infrastructural contracts without maintenance and the other model is for contracts with maintenance.

The models are not meant to be followed as rigid procedures. Their objectives are to provide guidance on the activities required for implementing RAMS into the design process. Some of the activities represented in the models can be carried out in different order while others can be discarded or replaced by other activities if they are not applicable for the project under
consideration. In addition, design process is an iterative process which means that the outcomes of certain activities may lead to changes in the design and this in turn means that previous analysis may need to be adjusted or performed again.

The proposed models are developed on the basis of a standard design process for infrastructural projects that is used in the Netherlands as described in the guide for Systems Engineering in the infrastructure sector. It worth emphasising here that, in the proposed models, RAMS is considered to be part of the design process rather than a control tool. The evaluation of the alternatives for example does not take place on the basis of RAMS only but on all other specified requirements.

During the development of the procedure described by the models, certain factors were taken into consideration to ensure the practicality of the models. These include the description of the procedure under main headings; structuring it and linking it to the design phases.

There are cases where there is no need for the contractor to start with the conceptual design phase due to the fact that part of the design is already performed by the client. In this case it is still possible to follow the proposed model by starting at a different point.

The proposed model for integrating RAMS for contracts with maintenance is shown in Figure 3. The procedure for these contract types is usually more extensive than in the case of contracts without maintenance. All standard RAMS activities are numbered on the basis of the phase in which they are required to take place. Subtle changes in the standard RAMS activities can be made through adding or removing activities to satisfy certain criteria.

Contracts with maintenance can also be of different forms such as DBFM or a pure maintenance contract. Depending on the form of the contract, the model can be followed at the point where the responsibility of the contractor starts. In DBFM contract this is usually at the conceptual design phase whilst in the case of a maintenance contract, for example, the start point would be at the operational phase at activity O2. Based on the outcome of the performance measurement system used, decision on what part of the procedure to follow in order to analyse and improve the system can be taken.

The model for the implementation of RAMS in contract without maintenance looks in principle similar to that shown in Figure 3 except for the exclusion of activities C5 in the conceptual design phase and activity O2 in the operational phase. Also activities C3, C8, P3, P9, D3, D8, E1 and E7 can be discarded in cases where there is little design freedom available for the designers. In some contracts that doesn’t include maintenance; the procedure on how to apply RAMS is specified in the contract. In this case the specified procedure should be followed instead of the proposed model. The proposed model can still be used however to complement the specified procedure.

VALIDATION OF THE MODELS

The proposed procedures have also been validated for their practicality and usefulness through workshops of experienced designers and RAMS engineers. The objective of the validation process was to check the practicality of the models and to improve them by finding answers to questions such as:

- How relevant are the criteria used in determining when and how RAMS is used?
Are the activities descriptions and order correct?
Are the activities positions compatible with the Standard System Engineering procedure normally used in the Netherlands?
Do the procedures provide improvement for RAMS application in the design process?
Do the proposed organisational changes provide an improvement in facilitating the integration of RAMS activities in the design process?

Figure 3: RAMS procedure for contracts that includes maintenance.

The validation process took place in two steps. The first involved presenting the procedures to the RAMS engineers to get their feedback on their practicality and whether they meet their...
objectives. The experts where asked to provide comments which were later used for adjustment of the procedures. In a following step in the validation process, the procedures were shown to a number of experienced designers to comment on their usefulness and practicality. The feedback comments were also used in refining the final procedures.

CONCLUSIONS

The paper has described some aspects of integrating design and engineering knowledge in construction. The research has shown that the implementation of RAMS and LCC in the design process of the construction infrastructural projects is still at its infancy. It has also shown that the important criteria that determine whether RAMS & LCC are used are ‘contract type’, ‘design freedom’, ‘evaluation criteria’, ‘project costs’ and ‘complexity’. Based on these criteria, two models have been proposed and developed for two types of contracts. The models have been validated by experts who have indicated the models’ usefulness and validity in meeting the RAMS requirements as well as improving the design process. The validation confirms that the developed procedures meet the requirements. The research has also indicated the importance of education and training designers about the subject to ensure successful implementation of the procedures. In addition, the work has shown that some organisational structural changes are required to achieve the objectives of using RAMS within the design process.

REFERENCES

CENELEC (1999), Europese Norm 50126 – Railway applications, the specification and demonstration of reliability, availability, maintainability and safety, European Committee for Electrotechnical Standardization, Brussels.


