Effects of modular building services distribution on construction sequence, time and cost

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Summary
The use of prefabricated or modular building services calls for a restructuring of the traditional construction procurement process. Project duration is affected by many factors, including a changed design, the introduction of a manufacturing process, differing resource demands, skill levels and costs. Risk management techniques are used to assess traditional and changed procurement routes and life cycles, identifying areas of greatest risk within the project, and the owners of that risk. The paper discusses two perceived construction procurement routes, concentrating on the building services – ‘traditional’ and ‘ideal’ – and their inherent risks. This allows for a fuller understanding of uncertainties present in the construction process, particularly those relating to building services. The risk management approach may be used to advise on the most suitable procurement route for particular types of project.

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Introduction and Background

Off-site manufacture, prefabrication, or modular construction – none of these terms are new in the building and construction industries. The application of such ‘manufacturing’ approaches in construction has existed for decades, but it is only recently that it has been seriously considered in the UK building services industry as a possible answer to improving quality and productivity [1]. The use of prefabrication, together with standardisation, was strongly advocated by Egan [2], who claimed that advantages ‘include speed of construction, lower cost, reduced need for skilled labour and achievement of zero defects.’

Latham [3] suggested that the UK construction industry needed to significantly improve productivity, and the Egan Report proposed mechanisms by which this might be realised. In order for such a goal to be achieved, Egan recommended that project processes restructure themselves around four key elements: product development, project implementation, partnering the supply chain and production of components; standardisation and preassembly are an integral part of this last element. “In the manufacturing industry, the concept of ‘design for manufacture’ is a vital part of delivering efficiency and quality, and construction needs to develop an equivalent concept of ‘design for construction’”. Recent literature on prefabrication is strongly allied to these reports and can in some cases be seen to be a consequence of them [4], [5]. Through an increase in productivity it is anticipated that costs will decrease (by as much as 30%), work will become more efficient and take less time.

Since the mid-1990s, several articles have appeared in the trade press, describing off-site (or modular) construction of building services, and the projects that this methodology has been applied on. These articles, for example [6] and [7], have mentioned time and cost-savings as the major benefits of off-site manufacture. The trade press has concentrated its efforts mainly on one building services contractor/manufacturer, although there are now increasing numbers of manufacturers operating within the M&E sector. An example of the type of solution offered is shown in Figure 1 (b).
Building services carry a large risk aspect on many projects – they are known to have the largest profit margin within the construction process, and form on average 30-40% of the total project value [8], but may conversely be the biggest loss leader.

The paper examines the effects of modular building services distribution on the construction process. It is recognised that procurement routes are rarely chosen for their benefit to the building services aspect of a project, but for the project as a whole [8]. The paper addresses the inherent risks in two procurement routes selected by the authors, where building services feature heavily. One is the perceived ‘traditional’ route; the second might be considered to be the ‘ideal’ route for projects where modular services are used. The reality is a ‘hybrid’, a path currently taken by the majority of projects utilising modular services distribution; it lies somewhere between the ‘traditional’ and ‘ideal’. Further explanation is provided in the methodology section.

The recognition of some of the risk areas in each of the above processes aids in the identification of the risk owners. Risks occur at different stages throughout the processes, and this recognition allows for management to make decisions about the actions that need to be taken in order to prevent, or minimise, identified risks [9].

**Methodology – Identification of Procurement Routes in Construction**

For the purpose of clarification, the authors identified three distinct procurement routes during the course of the research – ‘traditional’, ‘hybrid’ and ‘ideal’. Below is a summary of each.

**‘Traditional’ Construction Procurement**

In ‘traditionally’ procured construction projects, building services and structural design are not integrated. In most cases construction is well under way before any thought is given to the building services design; the design and construction of M&E services are, generally, overlapping processes. This results in problems associated all to often with building services, including too many visits by too many trades, leading to greater health and safety risks, and questions over maintenance and access issues.

Building services are not considered at the front-end of the project, thus resulting in work hastily being completed in difficult conditions; services distribution and installation are often unplanned processes. The team is fragmented, thus leading to dissatisfaction in many areas.
‘Hybrid’ Construction Procurement

The ‘hybrid’ model was identified through examination of current (live) projects as case studies, in combination with interviews gathering knowledge and experience from professionals working in this field. Twenty six organisations were visited as part of this information gathering process, with more than forty individuals contributing; these included main contractors, consultants (designers), manufacturers, cost consultants, architects and clients.

In the ‘hybrid’ process, initial structural design requires adaptation to accommodate off-site manufactured building services. There is greater co-operation between the members of the project team, although fragmentation is still in evidence. The biggest obstacle to improving on this process is a lack of knowledge and skill transfer from project to project. Individuals often learn ‘on-the-job’; once the task is complete they move on, taking what they have learned with them. A more effective learning process leads to the perceived ‘ideal’ route [10].

‘Ideal’ Construction Procurement

It is envisaged that in this process all aspects of design (architecture, structure and building services) are carried out in parallel, thus allowing greater integration and co-operation between members of the project team. Lines of communication are clear and transparent, and the aim of the team is to reap maximum benefit from the use of modular services distribution for all involved; this is achieved by sharing knowledge, experience and best practice down the supply chain.

Risk Management in Construction

There are many factors in building services construction which are uncertain, for example design, manufacture and installation time; their effects on the overall project duration; differing resource demands; potential errors involved in traditional and prefabricated installation of services distribution; training requirements of operatives and professionals, and costs. These uncertainties present risks to members of the project team. Since risk is present, it must be controlled. This is done using a risk management approach. This paper considers risk arising in project duration and cost; however, the method may be applied to all of the identified areas of uncertainty.

The process of risk management can be considered to consist of three phases – risk identification, risk analysis or measurement, and risk response or management [11].

The management of risk in construction is vital to the success of a project, and much work has been done to improve our understanding of and capacity for minimising risk. Various strategies have been developed which aid in the process of risk management [12].

Construction itself forms a relatively small part of the whole procurement process and life cycle of a project, and this is reflected in perceived risks within the construction industry [13]. The biggest risks are associated with contracts, project finances, and design.

Risk Identification

Risk identification is the most difficult task of risk management. It is necessary to ensure that all risk areas have been recognised, in order to be able to manage them effectively. The nature of the research is such that much of the information collected was subjective; however, there was strong agreement amongst those taking part in the identification of risks and factors which affect decision-making during the lifetime of a project.

For the selected procurement routes, the authors identified the most important areas of high risk within the building services process; uncertainties arise throughout the initial building
services design and integration with the structure itself, throughout the construction and installation process, and in the commissioning and handover phases.

Further interviews were carried out with construction engineers, to identify areas of risk on a ‘typical’ project (to ascertain whether these confirmed the researchers’ initial work). The project was a standard office building, eight storeys high; two scenarios were presented to the engineers – one where the project is traditionally procured, and the other where modular building services distribution is introduced (the ‘ideal’ process).

Risk was identified in terms of activity and process duration. The professionals in question gave their opinion on the length of time the project would take in both situations. These data were used to produce triangular distributions (so-called because of their shape, as seen in Figures 6 and 7). They indicate the amount of uncertainty, and hence risk, present in the process. Monte Carlo Simulation was used to determine the total uncertainty associated with each procurement process.

Monte Carlo Simulation is a technique that simulates a project by choosing random values for each of the variables in order to calculate potential outcomes for the project [14]. Multiple iterations are carried out (5000 in this case). Several graphs are presented in this paper, illustrating the outcome of Monte Carlo Simulation for the project in question; the chosen variables are activity or process duration, project duration, and cost.

‘Traditional’ Projects

A traditionally procured project has many areas of risk associated with it; some of these are directly related to M&E services, and are considered below.

The design and construction of building services traditionally suffer due to a lack of information about the system. It is not deemed necessary to provide the building services engineer with an upfront design. Installation is also often unplanned, thus adding further complications.

Construction quality is a major issue for traditionally procured building services. The services system is the last major part of construction and installation. The space within which the services are installed is restricted, and often cramped with more than one trade completing its part of the works. Due to a lack of full design and layout information there is little order to what occurs within the service voids. Consequently, the quality of workmanship suffers.

Management of risk is significantly increased on a traditionally procured project; there are more individuals on site, carrying out more activities. This not only contributes to logistical problems, but also introduces greater concerns for welfare and safety on site.

‘Ideal’ Projects

On ‘ideal’ projects using off-site manufactured services, the complete design is carried out at the beginning. This ensures that the necessary information for service module production is available, and manufacture can begin immediately. In practice it is rare for all of the information to be available; however, module manufacturers are making their needs known to the rest of the project team through education. This approach aims to make the ‘ideal’ a reality.

The manufacture of service modules is timed such that the core of the building is complete and awaiting their delivery. In such situations it is envisaged that the building structure and the modules themselves are ready at the proposed time, thus allowing full benefits to be reaped from their use. If the structure or the modules are delivered later, or earlier, than expected, this causes substantial delays in the construction phase. Strict adherence to the programme thus ensures that risk is greatly reduced.
Uncertainty in Project Duration

The following screen shots represent several risk analyses, using Monte Carlo Simulation, of a traditionally procured project, and of the perceived ‘ideal’ counterpart. Durations are in weeks, and are illustrated by the middle segment on each bar ■. The outer parts ■ represent uncertainty, i.e. the activity could, in theory, be taking place at any time illustrated by the combined sections of the bar. Figures 2 and 3 illustrate the duration for each type of project.

Figure 2. Uncertainty in duration for ‘ideal’ projects using modular building services

Figure 3. Uncertainty in duration for ‘traditional’ projects

From the diagrams it is possible to ascertain that the duration of the traditionally procured project is longer than that of the ‘ideal’ project using modular services. From the calculations, the theoretical maximum time for an ‘ideal’ project using off-site manufacture of building services is 149 weeks, whilst on a traditional project this figure rises to 158 weeks.
Cost – Time Graphs

From the cost-time graphs (Figures 4 and 5) it is possible to see that there is a smaller cost-time distribution on projects using modular building services; this means that there is less uncertainty. This is further illustrated in Figures 6 and 7.

![Figure 4. Cost-time graph for ‘ideal’ projects using modular building services](image1)

![Figure 5. Cost-time graphs for traditionally procured projects](image2)

Distributions of cost and time

Figure 6 illustrates the theoretical distributions of cost and time for a project utilising off-site manufacture of building services. The theoretical maximum time (project duration), as mentioned previously, is 149 weeks, 9 weeks less than on a traditionally procured project (see Figure 7). The actual maximum cost of the project using manufactured services is £192,696, compared to an actual maximum cost of £213,546; this is a saving of £20,850 or 11% of the total cost of the project using off-site manufactured services.
Several other numerical outputs are produced during the Monte Carlo Simulation, such as mean durations, minimum costs and times, and actual and theoretical figures. These may all be used for comparison purposes, to illustrate the fact that a well procured project using off-site manufacture of building services outperforms a traditionally procured project in terms of cost and duration uncertainty.

Conclusions

It is worthwhile carrying out a risk analysis using a method such as Monte Carlo Simulation as different answers will be produced every time. The generation of such random results proves in the case of the chosen project that it is advisable to consider using off-site manufacture of building services, as the uncertainty in time and cost is certainly lower than on a traditionally procured project.
The issue of reduced cost is one which many professionals consider needs to be proven, in order to encourage the UK construction industry as a whole to move towards a manufacturing approach, and to consider the use of modular services. Currently, very little data is publicly available to substantiate these claims, although other benefits have been measured and extensively reported. However, this research has shown that projects may be modelled on information provided by those working in the industry, and that this, in turn, may lead to a greater uptake of modular building services distribution.

The analysis carried out in this research considers the project up to the point of completion of construction. Many risks only become apparent after this phase; for example, the quality of the services and their installation and the ease of their maintenance can only be determined once the building becomes operational, and the users of the building begin to interact with it.

Further analysis on whole project life-cycles is advisable, in order to determine how traditional and innovative building services perform in practice, post construction. This may be the only true measure of all potential benefits for the whole project team. Further work in this area is strongly advised.

References


