THE DYNAMIC CONSTRUCTION WASTE GENERATION BEHAVIOR AMONG SUBCONTRACTORS IN SINGAPORE

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ABSTRACT

This paper introduces the application of system dynamics to the complex problem of construction waste generation among contractors in the Singapore construction industry. On a broader spectrum, it demonstrates how highly complex problems can be dealt with through the use of system dynamics methodology. Archival research on waste minimization issues was followed up which provided the necessary variables for the construction of the system dynamics construction waste minimization model.

The system dynamics model is presented to explain the construction waste generation waste behavior exhibited by the contractors on site in the Singapore construction industry. The model shows that several fundamental factors, ranging from subcontractors’ performance to wasteful culture, were the main causes of waste generation among contractors on site. The proposed model can be a useful tool for contractors in their decision-making related to construction waste minimization. Contractors are the frontline operatives who make decisions on construction methods and processes. The model can be used to help develop strategies, policies and best practices for contractors to reduce waste on site.

Keywords: Construction and demolition waste, waste minimization, main contractor, sub-contractor, system dynamics model

INTRODUCTION

The construction industry is deemed to have real and potential adverse impacts on the sustainable development. The large amount of construction and demolition waste produced in construction is one of the main problems of the industry in Singapore. Therefore, there is an urgent need for contractors to minimize the construction and demolition waste they generate.

The purpose of this study is to establish a construction waste minimization model for contractors in the Singapore construction industry based on systems thinking. It uses the system dynamics method as a tool, to illustrate the relations and interactions among the factors in construction waste generation. The model established in this study attempts to depict the construction waste generation trends on site in the Singapore construction industry.
This study explored the feasibility of using system dynamics to solve real problems and show how problems of great complexity could be dealt with. The proposed model can be a useful tool for contractors in their decision-making related to construction waste minimization. Contractors are the frontline operators who make decisions on construction methods and processes. The model can be used to help develop strategies, policies and best practices for contractors to reduce waste on site.

CAUSES OF MATERIAL WASTE ON SITE

The construction material waste problem is a complex one which extends beyond the site, both in its causes and its implications. Construction waste generation on site may occur due to one or a combination of many factors. [Gavilan and Bernold, (1994)] organized the sources of construction waste under six categories: (1) design related; (2) procurement related; (3) handling of materials related; (4) operation related; (5) residual related; and (6) “others”. Similarly, [Ekanayake and Ofori (2000)] categorized the causes of waste under: design; operational; material handling; and procurement.

Some researchers have attempted to classify causes of construction waste under different categories. According to [Low and Tan (1997)], under the Just-In-Time concept, the causes of construction waste can be classified as waste from (a) over-production; (b) delays; (c) transportation; (d) unnecessary processing; (e) excess inventory; (f) unnecessary motion; and (g) defects.

[Guthrie et al. (1998)] suggested that wastage of any material and components on the site can be directly attributed to one of the following: damage and spillage; contamination; storage beyond use-by date; over supply; out of specification; and theft and vandalism. This paper identified 4 main causes of construction waste. They are wasteful culture, subcontractors’ performance, qualities of recycled construction material and subcontractors’ co-operation and participation.

RELATIONSHIP BETWEEN LABOUR SUBCONTRACTING AND CONSTRUCTION WASTE

The Singapore construction industry is inherently labour intensive [Wong, (1990)]. Under such conditions, labour subcontracting is the most common employment practice in the industry. It involves casual employment of labour [Ofori and Debrah, (1998)]. This provides flexibility to the main contractors in terms of staffing. Unfortunately, it is possible that the problem of construction waste generation in the industry may be caused, at least in part, by this system.

The labour subcontractors on which the Singapore construction firms depend have no responsibility for purchasing materials. Although they are mainly concerned with producing work of reasonable standard, they are not interested in finding or adopting the most materials efficient way of producing their output. Their main concentration is on completing the maximum quantity of construction work within the shortest possible time [Wong, (1990)]. All too often there is evidence that they have little pride in their works and they are pre-occupied with their remuneration. As such, they are unlikely to concern
themselves with new working methods that reduce waste. Furthermore, a large proportion of the construction industry’s workforce is unskilled. The availability of this large pool of cheap unskilled labor has contributed to not only poor construction productivity but also high levels of wastage. Poor workmanship and the incorrect use of tools also result in a need for much remedial works and operational wastage [Wong, (1990)].

Although the traditional labour subcontracting system adopted in Singapore’s construction industry has various benefits and offers the main contractor a great deal of convenience, there are also drawbacks inherent in the system that are detrimental to the construction industry as a whole. [Ofori and Debrah (1998)] highlighted five drawbacks of using the system. They are: (i) wastage of materials as the subcontractors’ workers are most concerned with the quickest, not necessarily the most efficient methods; (ii) poor workmanship as the subcontractors do not invest in training, and switch workers from site to site to achieve the best return from the expenditure on them; (iii) improper usage of the main contractor’s equipment by the subcontractors’ workers; (iv) the subcontractors are unable to retain workers, or seek their improvement and welfare, leading to failure to develop a core pool of construction workers; and (v) the subcontractors’ workers do not enjoy permanent employment, perks or welfare benefits normally relating to such employment. Many authors highlight the potential contribution that labour subcontractors can make to improved performance of the main contractors, and the construction industry as a whole. For example, [Ling and Teo (2001)] also found that subcontractors play an important role in reducing wastage of concrete.

It can be seen that both the drawbacks and benefits of the employment of labour subcontractors have an impact on the different players of the industry. On the one hand, with no better alternatives, the labour subcontracting system is beneficial to the main contractors; on the other, considering the industry as a whole, the above drawbacks highlight one of the main causes of waste generation in the industry.

**IMPLICATIONS OF CONSTRUCTION AND DEMOILITION WASTE**

Numerous studies have dwelled on the general problem, which led to low levels of productivity in the construction industry [Bishop, (1975), Lewis, (1987)]. Studies have pointed out that one of the factors that contribute to low productivity on site is the inefficient management of construction resources — namely manpower, machinery and materials, leading to wastage [Malcolm et al., (1987)]. Costs are incurred for the clearing, removal and disposal of waste. The waste materials may cause damage or inconvenience such as blockage of drains [Lam, (1998)].

Lam [1998] found that projects could be delayed due to the non-availability of new materials to replace the wasted material. Even if the replacements are available, the cost of new materials may be higher than the initial purchases. Both situations are likely to increase the project costs. The unavailability of the wasted materials may force the use of inferior materials or materials that are less compatible, resulting in a building of poorer quality.
Need for proper waste minimization

Waste is often the result of the inefficient use of a natural resource. Therefore, waste management seeks to reduce the amount of waste produced as well as to reduce the environmental impact of that which is unavoidable. Some construction wastage is unavoidable in the building industry. However, it is necessary that wastage be controlled at an acceptable level as high wastage means high cost, low productivity, wasted labor, reduced cost competitiveness.

The usual methods of disposal of waste in landfills and under-utilization of natural resources have created adverse effects on the environment [Lam, (1998)]. Contaminated sites are no longer suitable for any kind of development. There is also permanent alteration to the physical environment and a depletion of natural resources. Therefore, waste generated in demolition and construction operations must be handled appropriately.

Proper waste management does not mean sending the waste to landfills, where they will be “covered up” for good [Kok, (1996)]. It is to exploit the possibility of minimizing or recycling the waste and utilizing them in other areas. Much of the material wastes generated in construction sites are not accounted for because they occur in “negligible” amounts. To ensure full utilization of land and natural resources, a proper waste management system should exist.

RESEARCH METHOD

The study was developed on the basis of, and conceptually supported by, a literature review in the area of labor subcontracting in Singapore which indirectly results in waste generation. System dynamics methodology is used in this paper to illustrate the relation and interaction among the corresponding factors in construction waste generation. The model established in this paper attempts to depict the construction waste generation behaviour among subcontractors in the Singapore construction industry.

The detailed literature review was essential so as to gain an understanding of current knowledge on waste minimization strategies. A study on the specific waste minimization strategies to be adopted by contractors to reduce waste generation was also undertaken. Additional information was assembled from published works. Subsequently, the system dynamics construction waste minimization model was constructed using variables obtained from the literature review.

OVERVIEW OF SYSTEM DYNAMICS METHODOLOGY

System dynamics modeling

System dynamics has its own paradigm and has established itself as a powerful methodology [Mohapatra and Mandal, (1989)]. It has been used to analyze industrial, economic, social and environmental systems of all kinds, since it was developed initially from the work of Jay W. Forrester [Forrester, (1961)]. In this study, the concept of system dynamics modeling has been used to examine the effect that one variable has on another.
System dynamics principles have been used to map and identify the major variables that influence waste generation and to distinguish the main feedback loops.

The qualitative model developed in this study would thus provide insights into the causal nature of the waste problem among subcontractors. This will provide subcontractors in construction with a richer understanding of the interdependence between waste causes and the effects of waste management.

**Discussion of model**

It is hoped to demonstrate the idea that system dynamics models can enable both main contractors and subcontractors to better understand how construction and demolition waste occur in construction projects. The adoption of such specific technology is necessary since no mental model can adequately assess the negative environmental impacts and high wastage caused by construction and demolition wastage.

**MODELING OF THE WASTE PROBLEM**

Figure 1 depicts the four main causes of construction waste minimization from the perspective of the main contractors. Often, construction materials are supplied by the main contractor to the subcontractors. Therefore, if the subcontractors adopt a wasteful culture, there would likely be an increase in construction waste generation. Furthermore, as illustrated in Figure 1, main contractors and subcontractors who practice construction waste minimization must ensure that the recycled construction materials should be of good quality. Otherwise, it would indirectly increase construction waste generation. Figure 1 also reveals that poor subcontractors’ performance would lead to a higher construction waste generation. Another point to take note of is that without adequate subcontractors’ co-operation and participation in relation to waste minimization issues would as well result in an increment in construction waste generation on site.
In this study, the concept of system dynamics modeling has been used to examine the effect that one variable has on another. Systems dynamics principles have been used to map and identify the major variables that influence the incidence of construction waste. This approach has assumed a holistic view of the project organization, by focusing on the behavioral trends and the relationship between the main contractor and subcontractors. General assumptions about the behavior of construction waste in a project system have been determined by using influence diagrams. These diagrams were integrated to develop a conceptual causal loop model (see Figure 2), to determine the overall causal structure of construction waste. The model can be used to identify the main feedback loops, which can be used to determine the major variables that influence construction waste. The qualitative model developed in this paper provides insight into the causal nature of construction waste in a project system.

The system dynamics construction waste minimization model developed in Figure 2 will enable the contractors to unravel a series of complex problems, relating to construction waste generation on site, into more manageable interrelated components. It is suggested that emphasis should also be placed on understanding how the dynamic relationship between the main contractor and subcontractor can have an impact on construction waste generation, so that appropriate responsive actions can be taken in order to maximize the effect of positive dynamics and minimize the effect of negative ones.

*Source: Author*
Using the methodology of system dynamics, the major factors that influence construction waste generation have been identified and discussed. It has shown in Figure 2 that construction waste minimization initiatives such as stringent selection of subcontractors; training and development of subcontractors; subcontractors’ co-operation and participation in waste minimization issues and effectiveness of construction supply chain management that do have an impact on construction waste generation. Figure 2 stresses that implementing a proper control system over the main contractor-subcontractors relationship represent the first step in developing a holistic strategy for minimizing waste generation from the construction process.

This model can provide both main contractors and subcontractors in construction with a richer understanding of the interdependence between them and the management challenges associated with identifying effective construction waste prevention strategies. The system dynamics construction waste minimization model also encourages a paradigm shift in how one views the relationship between main contractor and subcontractors within a project system: away from the traditional mechanistic view to a holistic viewpoint. If construction waste is to be reduced or eliminated, contractors must focus on the whole system, rather than on individual parts.
CONTRIBUTIONS OF THE SYSTEM DYNAMICS CONSTRUCTION WASTE MINIMIZATION MODEL

Generally speaking, this model can help contractors select the appropriate waste minimization methods that will optimize a given policy variable in a construction process. The effect of system configuration on the performance of the system can be used to influence the design of the system, before the planning stage is implemented. This information is critical in developing an efficient construction waste minimization system, both on site and in the company.

The lack of attention to construction waste, especially during the construction process, has meant that construction waste has become an inevitable feature of the construction process and the loss of profit due to waste has been found by [Neo and Koh (1995)] to be exceptionally high. Such costs could be even higher because they do not represent other intangible costs relating to construction waste. To reduce waste generation on site, an understanding of its causal structure is needed so that effective waste minimization strategies can be identified and the effects of waste generation can be reduced or eliminated. The system dynamics construction waste minimization model suggests that goal setting and feedback, in relation to waste minimization policies between main contractor and subcontractors, can be used effectively to reduce the volume of waste disposed of in landfills and improve the efficiency of material usage in construction.

By and large, the model presented enables contractors to better understand the process of construction, in relation to the problem of waste generation and how it occurs in construction projects. Waste minimization policies need to be created and clearly communicated at project and company level by main contractors, such that visible performance requirements are properly understood by subcontractors. In addition, performance requirements to reduce waste must be promoted and imposed equitably at all levels by main contractors, so as to promote a sense of collective responsibility among subcontractors.

Insights drawn from the model suggest that main contractors need to demonstrate commitment to the issue of waste minimization and to provide the necessary infrastructure to help subcontractors reduce waste. Subcontractors’ involvement and cooperation is needed to ensure that waste minimization strategies can be successful. Similarly, effective construction supply chain management would provide an exchange platform for the exchange of construction and demolition waste materials between contractors, construction material and equipment manufacturers and recyclers, and landfill facilities operators. Thus, it would increase the quality of recycled materials and reduce waste going into landfills.

The model also reveals that it is important for training and development programs to be initiated by the main contractor or the respective statutory boards, for the subcontractors to increase their performance and productivity in order to minimize unavoidable construction waste on site.
CONCLUSION

Literature proposing the formulation of policies and the development of construction waste minimization strategies as it relates to functionality is not extensive, but clearly supports the idea that the standard for construction waste generation is dynamic. When policies are created, they are often vague and symbolic. The policies also tend to be based on theoretical assumptions, and the benefits they envisage can take some time to surface. Certain policies might be considered suitable in all circumstances, whereas others may only be tailor-made to suit special situations. Therefore, it is crucial for contractors to be able to adopt relevant construction waste minimization policies and practices.

One of the current problems in the construction industry is the lack of a model to evaluate waste generation on site. The significant outcome of this study is the system dynamics waste minimization model. The contractors now have a tool to help them to construct structures that produce the least waste on site. Contractors are the frontline operatives who make decisions on construction methods and processes. They can use the model to develop strategies, policies and best practices for their sites to reduce wastage. Introducing the system dynamics waste minimization model will lead the way to cultivate a waste minimization culture in the industry. This may eventually contribute towards sustainability and indirectly promote construction productivity, which is a top priority in Singapore today.

System dynamics takes an integrative perspective of developing system thinking capabilities. It uses system thinking as a conceptual tool for gaining insights into the structures that create the dynamic behavior often found in complex systems. One such system is the construction waste generation behaviour among contractors in Singapore. Furthermore it encourages a paradigm shift in how one views a project system, away from the traditional method to a holistic viewpoint. If construction waste is to be reduced, contractors must focus on the whole construction system and how all the parts of the system fit together.

REFERENCES


