MANAGING CONSTRUCTION WASTE THROUGH SYSTEM DYNAMICS MODELLING: THE CASE OF HONG KONG

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ABSTRACT:

As construction waste is the main waste generator in Hong Kong, its impact on the environment has become a serious problem to society. Although, construction waste management has received increasing attention from decision makers and researchers since the early 1980s, how to coordinate the factors involved in construction waste to minimise its impact on the environment still needs attention. This paper describes the development of a simulation model by applying system dynamics. This model provides a comprehensive view of construction waste management in Hong Kong. The model is designed to provide decision makes and associated stakeholders with a tool to evaluate construction waste management plans and to improve the environmental performance of construction waste strategies in Hong Kong, which ultimately will lead to the ways of better managing construction waste in the Pearl River Delta Region.

Keywords: construction waste, simulation model, system dynamics, and Hong Kong.

1. INTRODUCTION

Construction and demolition (C & D) waste management has become one of the major environmental problems in both developed and developing countries. It has been a pressing issue in Hong Kong since the late nineties. Tremendous amounts of C & D waste have been generated from ongoing new construction works, as well as renovation and demolition works. The C & D waste has been increased which has been resulted from the extensive building and infrastructure development projects as well as redevelopment of old districts. Figure 1 shows the quantity of construction waste from 1991 to 2004 (EPD 2005).

From the Figure1, it is found that part of C & D waste is disposed of at landfills. Although it is decreasing in its quantity, it still composes a major part of total solid waste disposed of at landfills. In this situation, not only a large amount of money is paid to handle C & D waste, but also valuable land is consumed for C & D waste disposal. It is reported that C & D waste has been costing the government more than HK$ 200 million per year for disposal and taking up valuable landfill space at a rate of about 3500 m^3 per day. Keeping with the rate, our landfills will run out around 2015. Nevertheless, it is necessary to forecast C & D waste quantities on site by using a method to be in line with the changes. The intent of this paper is to describe such a simulation model developed by using system dynamics to forecast construction waste on-site.

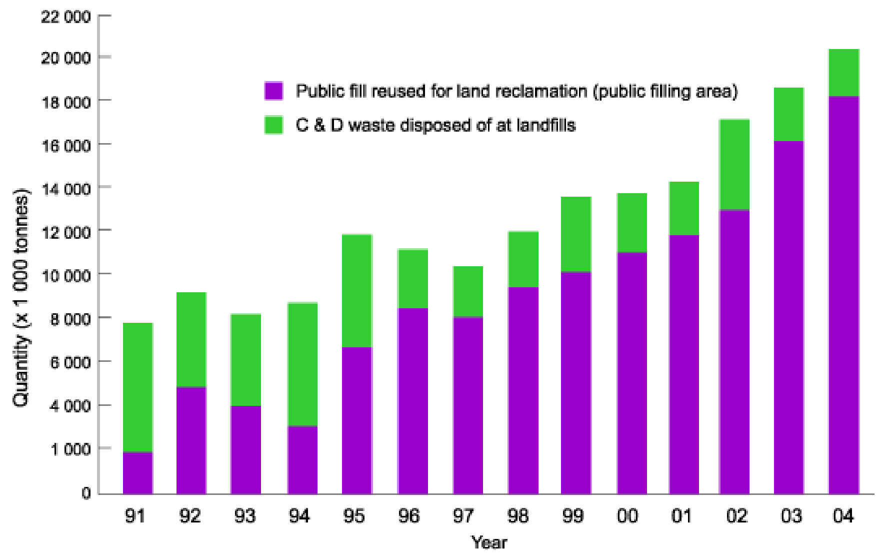

Figure 1 Quantities of Construction Waste in 1991-2004 (EPD 2005)

2. METHODOLOGY BY USING SYSTEM DYNAMICSS

A waste management mapping model has been developed based on some cases in Hong Kong to be used for guiding the waste controlling procedures (Shen, Tam, Tam, and Drew, 2004). However, wastage factors and waste handling procedures involved in C & D waste management have been viewed separately. No one has considered the inter-relationships between major decisions makers involved in C & D waste management. The whole business of waste management can essentially be viewed as one system all linked to the physical waste process because it involves different decision makers, disciplines and activities. With this in mind, waste management can be considered as a complex system, with inherent characteristics for planning, organising, and co-ordinating all activities.

System Dynamics (SD), originated by Forrester (1958), is a system analysis approach that is concerned with creating models or representations of real world systems and studying their dynamics. The modelling approach focuses upon an understanding of feedback and feed forward relationships, and the model construction requires the analyst to construct the relationships between the various stage variables and rate variables. As a result, system dynamics is often used as a methodology for improving the soundness and effectiveness of the decision-making process and, in recent times, has become a popular technique for modelling construction project management (Sterman, 1992; Rodrigues & Bowers, 1996; Li, Love and Drew, 2000; Shen, Li, Love and Mandal; Hao and Scott, 2001). It can be seen that by using the similar approach and methodology will throw some light for C & D waste management. Although system dynamics has been widely used in different fields of project management, the area of C & D waste management has not benefited enough from this modelling approach. Only a few published articles can be found.

Mashayekhi (1993) carried out a comprehensive study on the transition in New York State solid waste system, which incorporated qualitative analysis in its system dynamics model. Sudhir et al. (1997) further identified the difference of solid waste management system between developed countries and developing countries. It was suggested that both formal and informal systems operate at the same time in the developing countries. Therefore, a system dynamics model relevant to the issues in developing countries, specifically to the Indian context, was developed. Karavezyris et al. (2002) applied system dynamics to forecasting of municipal solid waste. In order to incorporate qualitative variables used for modelling exogenous elements like influences and thresholds, fuzzy logic was integrated with the system dynamics tool. To resolve the scarcity of complete historical records of solid waste, a system dynamics model based on grey dynamic model was developed for prediction of solid waste generation in a fast-growing urban area (Dyson and Chang 2005). From the view of the whole life cycle of a construction project, Hao et al. (2006) developed a simulation model based on system dynamics methodology for strategic planning of C & D waste in Hong Kong.

3. SIMULATION MODEL DESCRIPTION

C & D waste management for construction on site

One of the most effective mean is on-site sorting of C & D waste (Poon et al. 2001). C & D waste usually involves two types of material: the inert waste, which comprises mainly sand, bricks and concrete, and the non-inert waste, consisting of materials such as bamboo, plastics, glass, wood, paper, vegetation and other organic materials. By separating the inert waste from the non-inert waste, the inert waste could be used for land reclamation and only the non-inert waste will be disposed of at landfills. The strategy minimizes the amount requiring final disposal so that the life span of the landfills can be extended.

However, the strategy is not fully implemented by construction companies. The major barriers attributes to increase in management and operation costs, lack of trained staffs and expertise, lack of government legal enforcement, and so on (Shen and Tam 2002). Increase in cost may be the most concerned factors of contractors and other stakeholders. A recent survey of the Hong Kong construction industry also showed that the conception that environmental management results in many more costs than benefits is prevalent among contractors (Shen and Tam 2002). As companies always seek to maximize profits, it is natural that contractors are reluctant to adopt environmentally friendly measures of waste management.

In 2004 the Legislative Council passed a bill, The Waste Disposal (Amendment) Ordinance 2004, which is the enabling legislation for the Charging Regulation and the Designated Waste Disposal Facility (DWDF) Regulation and provided the statutory basis for the introduction of the construction waste disposal charging scheme. The Charging Regulation and the DWDF Regulation set out the details of the construction waste disposal charging scheme, including the charges for the disposal of construction waste at landfills, sorting facilities and public fill reception facilities and their calculation. The Charging Regulation sets the disposal charges at HK$125 per tonne at landfills for waste that contains less than 50% inert material, HK$100 per tonne at sorting facilities and HK$27 per tonne at public fill reception facilities in order to fully recover the capital and recurrent costs of the facilities according to the polluter pays principle (EPD 2006). The charges scheme will come into effect on 20 January 2006.

Waste generation

Generally, the quantity of generated waste varies through construction process. The quantity and composition of the waste highly depend on the building structure type and the technology used to build the structure. Specially, it is noted that the quantity of waste is highly related to that of purchased building material. Shen et al (2004) estimated that about 1-10% by weight of the purchased construction materials, depending on the type of material, leaves the site as waste.

On site sorting

As aforementioned, on-site sorting is an effective means to reduce the quantities of C & D waste to be disposed of at landfills. However, on-site sorting is not yet a common measure in construction because the prerequisites such as enough site space, skilled workers, and investment in necessary equipment have to be met to operate the on-site sorting. Furthermore, the normal construction may be disturbed by the sorting work. Thus, it is not surprising that about 70% of the contractors would not perform on-site construction waste sorting unless it is specified in the contract (Poon et al. 2001). However, the execution of the construction waste disposal charging scheme will alter the attitude of the contractors to the on-site sorting. When the charges scheme comes into effect, on-site sorting will become popular because it may decrease the total cost of waste disposal.

Model development

The most popular system dynamics software is Stella®. It is a multi-level, hierarchical environment for construction and interacting with models. The software enables users to modelling interrelationships, which constitute a process, a strategy or an issue, by user-friendly visual tools on the interface. The modelling and simulation capabilities of the software are ideally suited for capturing the operational dynamics and complexities of management issues depicting them as a flow chart or schematic.

The model depicting the C & D waste management for construction on-site is developed using the abovementioned software package. As shown in Figure 2, C & D waste is generated from building construction activities. The quantity of C & D waste is determined by the quantity of purchased building material and waste ratio. The quantity of purchase building material varies with construction schedule. It can be calculated by adding the needed materials of all activities implemented simultaneously according to project schedule.

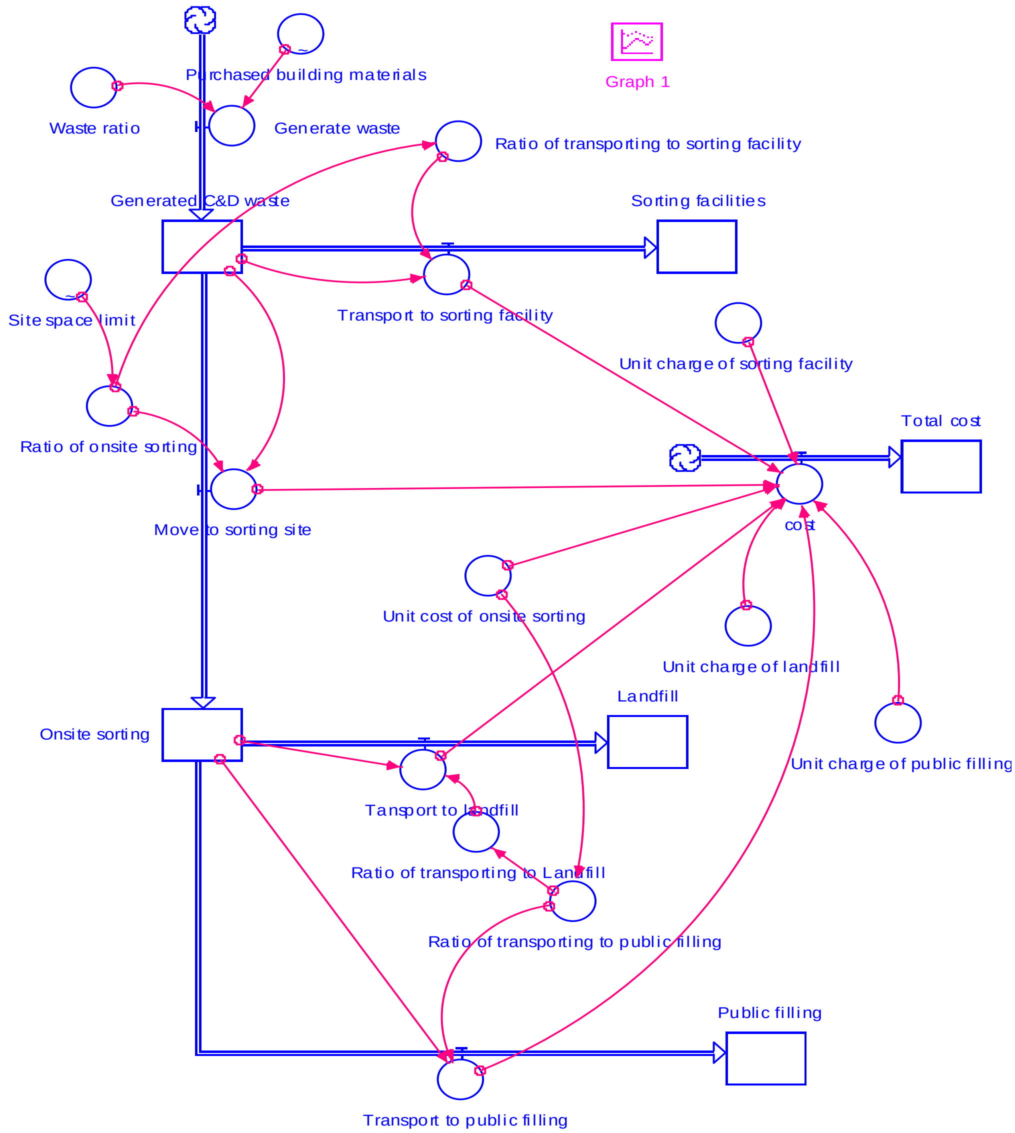

Figure 2 Simulation model for C & D waste management on-site

There are two ways to handle the generated waste. One is to transport the waste directly to sorting facilities with the charge of HK$100 per tonne. The other way is to adopt the on-site sorting before disposal at landfills or public fillings, because the landfills do not receive the waste that contains more than 50% inert material. The ratio of waste further moved to on-site sorting is in relation with the availability of site space, because the implementation of on-site sorting is restricted by the site space. For congested building sites in urban areas, it is difficult to find enough space for setting up sorting facilities and equipment. Moreover, the sorting process may interfere with normal construction activities and result in delay of completion date and increase in cost. So, the more limited the site space is, the more low the ratio of on-site sorting is.

On-site sorting involves labours and facilities such as containers, rubbish bins. Different construction waste sorting schemes need different quantity of the labors and facilities. For example, only a few of containers are setup on site for separate collection of the inert waste and non-inert waste in a simple sorting scheme. The scheme only results in a little increase in investment including the cost of containers and the fee of training frontline workers. However, the separation is usually not complete due to lack of management and guideline. To improve the separation percentage of inert waste to the total waste, manual sorting is needed to further separate the inert waste from the non-inert waste. The corresponding cost of sorting is augmented at result of increment in skilled labors. Thus, in this model the ratio of separated inert waste is determined by the unit cost of on-site sorting. After separated through on-site sorting, the inert waste is transported to public filling with the charge HK$27 per tonne. Whilst the remained non-inert waste or mixed waste that contains less than 50% inert material is delivered to landfill with charge HK$125 per tonne.

4. SIMULATION RESULTS AND DISCUSSIONS

Data input

As aforementioned, waste generation depends mostly on the performance of the construction operation and the schedule. The simulation model incorporates the construction schedule in relation to the generation of waste. The quantity of C & D waste is determined by the quantity of purchased building material according to the schedule and waste ratio. It is estimated that 10% of the materials is the waste generated from new construction projects in this research. The monthly quantity of purchased building material according to the construction schedule is shown in Figure 3. The construction duration is 12 months, and the quantity unit of the material is 1000 t per month.

Ratio of on-site sorting determined by site space limit is a number in scale of 0 to 1. If there is no space for placement of waste containers and operation of on-site sorting, the ratio of on-site sorting is 0. By contrary, the space is large enough to adopt the on-site sorting; the ratio of on-site sorting is 1. Sometimes the ratio of on-site sorting is a number between 0 and 1 because the site space is congested and only a fraction of needed space is supplied. The ratio of on-site sorting may vary with construction schedule, too. Once the ratio of on-site sorting is determined, the ratio of transporting to sorting facility is calculated as Ratio of transporting to sorting facility = 1- ratio of on-site sorting.

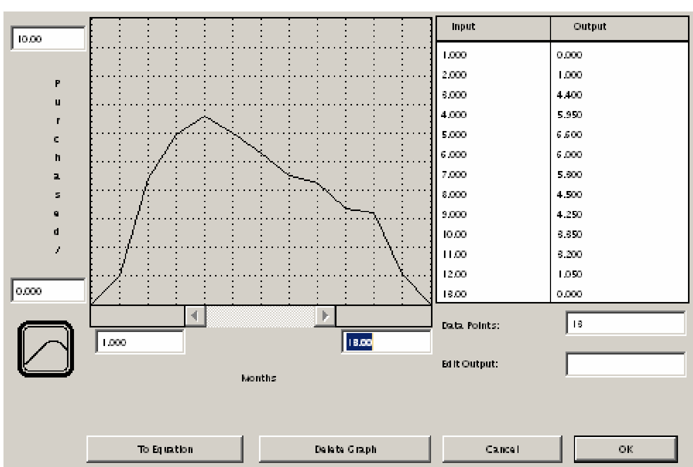

Figure 3 The monthly quantity of purchased building material

As aforementioned, unit cost of on-site sorting is different in various waste sorting schemes. More cost has to be paid for a scheme with a higher separation percentage of inert waste to the total waste (namely, ratio of transporting to public filling). In this paper, two sorting schemes are considered.

Scenario 1:
Only on-site sorting facilities and training for frontline workers are adopted. The unit cost of on-site sorting is HK$5 per tonne and ratio of transporting to public filling is a random number scale from 70% to 80%.

Scenario 2:
Apart from on-site sorting facilities, the manual sorting is also adopted. The unit cost of on-site sorting is HK$15 per tonne and ratio of transporting to public filling is a random number scale from 80% to 90%. Similarly the ratio of transporting to landfill is calculated as Ratio of transporting to landfill = 1- ratio of transporting to public filling In addition, the unit charges of sorting facility, landfill and public filling are respective HK$100, HK $125 and HK $27.

Simulation result analysis
After all the variables are determined, simulation can be performed. Figure 4 shows the variation of total cost of waste disposal depending on the ratio of on-site sorting. From the figure, it is obvious that the implementation of on-site sorting can dramatically decrease the waste disposal cost when the charge scheme takes effect. If the on-site sorting is completely adopted, the C & D waste disposal cost is only HK$ 2.36×10^5. Whilst the C & D waste disposal cost is up to HK$ 5.32×10^5, 2.25 times as the earlier, when on-site sorting is not implemented. In other point, the result reveals that the charge scheme will be effective to promote the reasonable disposal of C & D waste.

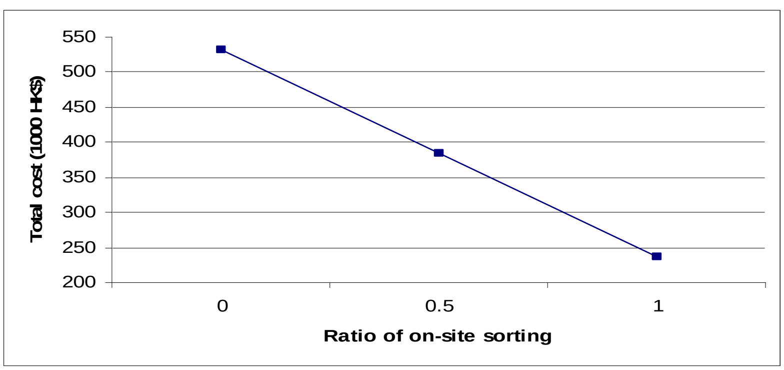

Figure 4 The total cost of disposal waste

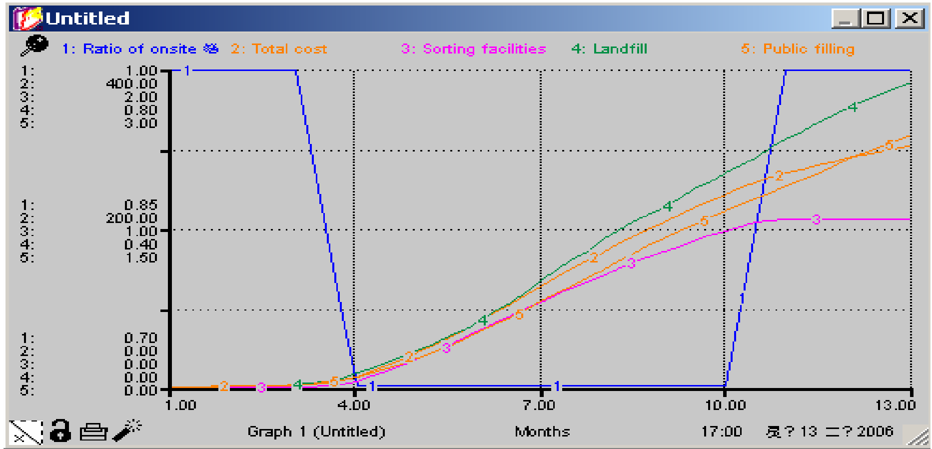

Figure 5 The simulation result on-site sorting scheme 1

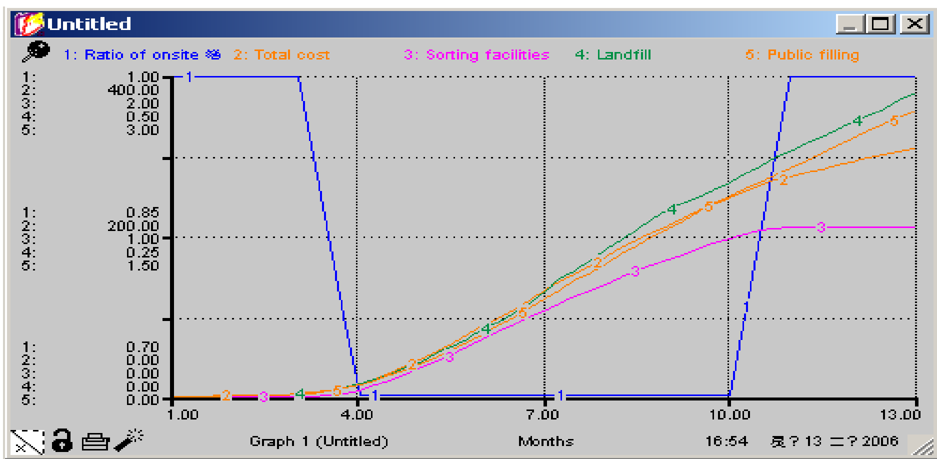

Figure 6 The simulation result of on-site sorting scenario 2

As mentioned above, the ratio of on-site sorting is limited by the limited site space. As the vacancy site space commonly varies with construction schedule, the ratio of on-site sorting is variable during construction process. To gain more practical result, the variation of the ratio is further taken into account of in the simulation. As shown in Figure 5, the ratios of on-site sorting are 1.0 in months 1-2 and 10-12, and decline to 0.7 through months 3-9 when a bulk of construction activities are implemented simultaneously and site space is congest. Accordingly, the total cost increases to HK\$ 3.05 $\times 10^5$. At the same time, the monthly quantity of waste disposal at sorting facilities, landfill and public filling are generated, which give the contractors more information to arrange the waste management plan.

From the simulation shown above, the on-site sorting scheme 1 is adopted. Subsequently the on-site sorting scheme 2 will be simulated for comparison. As shown in Figure 6, the total cost is HK\$ 3.10 $\times 10^5$, higher than that of scheme 1. Although the higher percentage of inert waste separation is achieved, more wages have to be paid to workers for manual sorting than the saving of disposal cost. In term of cost, the scheme 2 is better. After simulation, it is found that the implementation of on-site waste sorting is profitable for construction contractors for it decreases the total waste disposal cost dramatically. Furthermore, the on-site sorting scenario 1 is recommended because it costs less than scenario 2.

5. CONCLUSION

Study on enhancement of the waste management on site is an approach to address the problem. This paper presents a model developed by using system dynamics methodology to predict C & D waste generated on site. With the simulation model, contractors can gain deep insight into the C & D waste management system and make an optimum decision about the waste management scheme. The results from this model can be used to compare to other results. Since the model allows the users to fine-tune the input parameters, it is flexible to adjust the model to better reflect the reality according to different conditions. The model represents a relatively powerful tool for planning and policy analysis using available data. This is a well claimed advantage over other static models.

6. ACKNOWLEDGMENT

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