A model for evaluating the social performance of construction waste management

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A B S T R A C T

It has been determined by existing literature that a lot of research efforts have been made to the economic performance of construction waste management (CWM), but less attention is paid to investigation of the social performance of CWM. This study therefore attempts to develop a model for quantitatively evaluating the social performance of CWM by using a system dynamics (SD) approach. Firstly, major variables affecting the social performance of CWM are identified and a holistic system for assessing the social performance of CWM is formulated in line with feedback relationships underlying these variables. The developed system is then converted into a SD model through the software iThink. An empirical case study is finally conducted to demonstrate application of the model. Results of model validation indicate that the model is robust and reasonable to reflect the situation of the real system under study. Findings of the case study offer helpful insights into effectively promoting the social performance of CWM of the project investigated. Furthermore, the model exhibits great potential to function as an experimental platform for dynamically evaluating effects of management measures on improving the social performance of CWM of construction projects.

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1. Introduction

Construction activities are by nature not environmentally friendly due to the diverse adverse impacts such as resource depletion, noise, dust, air pollution and discharge of toxic waste (Lu and Yuan, 2011). Nowadays, all these impacts are forcing the construction industry to develop toward the mission of sustainability. To this end, many concepts have been emerging worldwide as an integral endeavor to develop and apply green practices in the construction sector, mainly including green building, sustainable construction, sustainable design, construction waste management and low-carbon building (Robichaud and Anantatmulu, 2011). As a result, many countries are placing efforts into the application of sustainable construction practices.

Among the culprits contributing to the adverse impacts of construction activities, a noteworthy one is the solid waste (termed as construction waste hereafter) caused by various building, renovating and demolishing activities. It is reported that every year an overwhelming amount of construction waste is generated worldwide, resulting in many economic, environmental and social problems, although varying from country to country. For example, the United States Environmental Protection Agency (US EPA, 2002) estimated that approximately 136 million tons of building-related construction debris is generated each year in the US, the majority from demolition and renovation (48% and 44%, respectively). Sandler and Swingle (2006) found that only 20–30% of generated construction waste in the US was recycled, while in the UK around 70 million tons of construction materials and soil ended up as waste (DETR, 2000) producing a wastage rate in the UK construction industry of 10–15% (McGrath and Anderson, 2000). In Australia, nearly 1 ton of solid waste was sent to landfill per person each year (Reddrop and Ryan, 1997), and construction waste was estimated to account for 16–40% of total MSW (Bell, 1998). In Hong Kong, the construction waste generated annually more than doubled between 1993 and 2004 (Poon, 2007). According to a report by Hong Kong’s Environment Protection Department, about 2900 tons of construction waste was received at landfills per day in 2007 (HKEPD, 2007). Furthermore, in 2008, China produced 29% of the world’s MSW, of which construction activities contributed nearly 40% (Wang et al., 2008). The problems resulted from construction waste are particularly grievous in developing countries partially because that on one hand, large-scale construction activities are occurring in these countries due to requirements of urbanization and infrastructure development, and thus resulting in huge amounts of construction waste (Wang et al., 2010); on the other hand, project decision-makers put much emphasis on traditional project objectives, namely, cost, duration, quality, and safety, rather than environment (Shen et al., 2006). Therefore, construction waste management (CWM) in these countries is still in the primary stage where related regulatory environment is immature and application of waste management practices is low (Lu and Yuan, 2010).

Fortunately, it is found that research efforts over the last decade have resulted in a number of studies dedicated to the investigation
of CWM (Teo and Loosemore, 2001; Tam and Tam, 2006; Yuan and Shen, 2011). These attempts are of vital importance to aid in the application of effective CWM practices (Yuan and Shen, 2011). As afore-mentioned, waste will either positively or negatively influence the economic, environmental and social performance of construction projects. However, a thorough literature search determined that the majority of research efforts have been focused on the economic and environmental impact associated with construction waste (Emmanuel, 2004; Duran et al., 2006; Yuan et al., 2011). Therefore, they fail to cover the social impact resulted from construction waste. As insisted by Yao (2009), sustainable construction in the long-run should embrace collective development of three major dimensions, namely, economic, environmental, and social aspects. The research gap of existing lacks in investigating the social impact with respect to CWM inspires the authors to undertake this study. Thus, the aim of this study is to investigate the social performance of CWM.

The International Association for Impact Assessment (IAIA) provides a definition for social impact assessment (SIA), which is “it includes the processes of analyzing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions. Its primary purpose is to bring about a more sustainable and equitable biophysical and human environment” (IAIA, 2011). An earlier study by Klang et al. (2003) proposed a model for evaluating the environmental, economic and social sustainability of demolition waste. By inputting data obtained from a practical case into the established model, social impacts of demolition waste were studied. The study finally suggested that data collection needed to perform this kind of analysis is resource-demanding, thus it would be better to identify a limited number of key indicators for assessment. Recently, Rocha and Sattler (2009) discussed the major factors influencing construction waste reuse in Brazil. In their study, the social impact was not separately examined but considered along with economic and legal factors. Meanwhile, the social impact associated with construction waste reuse was analyzed from a qualitative point of view.

The reasons for scant research into social performance of CWM are probably attributed to three aspects. Firstly, the social influence of performing CWM is by and large of lower priority while implementing construction projects. Mostly, the major focus is given to objectives such as project cost, time, duration and safety (Shen et al., 2006). Secondly, social impact is not always amenable to empirical measurement (Dale et al., 1997). Fundamentally, many indicators used for assessing the social impact of CWM are qualitative and thus very difficult to be quantified. Finally, implementation of CWM affects different groups of project participants in different ways. Major participants involved in CWM can be generally divided into two groups: one group includes the authorities, general public and NGOs. The other group comprises project clients, main and subcontractors (Yuan and Shen, 2011). It is obvious that the former group tends to concern more about construction waste minimization, aiming at lessening the environmental and social impacts, while the latter concerns more on the economic benefits from managing construction waste. Nevertheless, in most practices, particularly those developing economies, it is the latter group that is more powerful in developing and executing CWM plans. Hence, it is not surprising that more emphases are placed on assessing and monitoring the economic performance of CWM. But in line with an increasingly recognized consensus that the former group tends to concern more about construction waste minimization, aiming at lessening the environmental and social aspects, should be collectively considered for elevating the effectiveness of CWM, it imperative to evaluate the social performance of CWM.

2. Research methodology

2.1. Why is system dynamics?

The evaluation of the social performance of CWM requires a good understanding of the entire management process, ranging from construction waste generation to the final disposal. This process is defined by Yuan et al. (2011) as the construction waste chain. Traditionally, various components involved in CWM have been examined independently. But recent studies presented some key characteristics of the CWM system that researchers should envisage when investigating CWM issues, including: (1) the CWM is a complicated system which is demonstrated by the number of elements involved in the system, encompassing waste generation, reduction, reuse, recycling, and disposal; in addition, each of the CWM activities involves different stakeholders (Yuan and Shen, 2011); (2) elements in the CWM system are largely interdependent (Seadon, 2010); and (3) the CWM system is dynamic, which is different from the conventional CWM research that mostly tends to view the system from a static point of view (Yuan et al., 2011).

In line with this trend, many studies have been carried out by using system dynamics (SD) approach for investigating a diversity of topics in relation to the broad discipline of waste management, including CWM. Dyson and Chang (2005), for example, developed a SD model for forecasting municipal solid waste (MSW) generation; the study suggested that the model by using SD can capture the dynamic nature of interactions among major MSW components. By applying SD to hospital waste management, Chaerul et al. (2008) found that it is capable of keeping track of complex interrelationships and feedback loops among components in the studied system. Within the discipline of CWM, Yuan et al. (2011) presented a SD-based model for analyzing the cost–benefit of CWM activities; based on the findings, it is argued that SD provides a new vehicle for examining interrelationships of CWM components from a dynamic point of view.

Nevertheless, it is obvious from the discussion in the previous section that no research is conducted for dealing with the above characteristics of the CWM system when evaluating the social performance of CWM. Thus, an interdisciplinary approach such as SD will be an ideal method for fulfilling this aim. In this regard, the SD approach is employed in this study to assess the social performance of CWM.

2.2. A brief introduction to SD modeling

Since the origination of SD in 1961 (Forrester, 1961), it has been widely used in a vast range of disciplines for understanding different economical, social and environmental systems. It is capable of
dealing with complicated systems where different kinds of feedbacks exist. It is now a well-established methodology which allows researchers to describe systems of high complexity by using a series of intuitive tools, such as causal loop diagrams and stock-loop diagrams. These tools also make it easier to run established models in a computer for quantitative analysis. Readers are referred to Sterman (2000) for detailed guidelines on how to construct a SD model step-by-step.

Generally, SD modeling can utilize a five-step procedure to formulate a model, including (1) causal loop diagram, (2) stock-flow diagram, (3) building confidence in the model, (4) base run simulation, and (5) scenario analysis. The causal loop diagram is used to diminish the complexity of the system under study by abstracting the feedback loops which are of paramount importance to the behavior of the whole system. In this regard, the causal loop diagram intends to bring forward a conceptual model of the studied system. The stock-flow diagram is usually developed based on the causal loop diagram and visualized through professional software for quantitative simulation and analysis. Before the established model can be adopted for quantitative analysis, it is important to build confidence in it. A series of tests have therefore been suggested by Coyle (1996) for SD model validation. After going through these three steps, it is agreed that the model can be reliable for analysis which mainly includes base run simulation and scenario analysis. Base run simulation primarily helps understand the system “as-is”, while scenario analysis offers insights into management measures that would potentially ameliorate the current behavior of the system.

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2.3 SD modeling with the iThink software

Although different software applications are developed for SD modeling, this study uses the software iThink®, in which the entire modeling process can be handled by a user-friendly interface. Through iThink, all elements of the studied system can be represented by four components, namely, stock, flow, converter, and connector. A simple SD model containing these four components is exhibited in Fig. 1. It can be seen that a stock (social performance of construction waste management) collects all those in-flows (e.g. social performance increasing) and also serves as the source from where out-flows (e.g. social performance decreasing) come. A flow serves as a vehicle to deliver information to or drain information from the stock. The value of a flow can be positive or negative. A positive flow is an in-flow and will fill in the stock, and a negative flow is an out-flow draining the stock. A converter (e.g. positive impact of construction waste management) has a utilitarian role in selecting proper values and functions of parameters in the model. The connector is an information transmitter connecting elements (Yuan et al., 2011).

Based on the introduction above, a self-explanatory schematic diagram showing the model development process in this study is finalized (see Fig. 2).

3. Causal loop diagram

As defined previously, the model aims at examining major variables affecting the social performance of CWM, as well as their underlying causal relationships. This conceptual model in causal loop diagram, as shown in Fig. 3, comprises six feedback loops in total, among which one is negative (i.e. B1) and the other five are positive (i.e. R1, R2, R3, R4 and R5). The behavior of the entire system is determined through the dynamic interactions between these feedback loops.

By referring to feedback loop B1 (see Fig. 3), it can be seen obviously that a larger amount of waste disposed of illegally will raise the public appeal for regulating illegal waste dumping behavior. Under the pressure of reducing illegal waste dumping, both the local authorities and project managers will act to enhance the conduct of waste management. Particularly, the local authorities would reinforce the effectiveness of relevant regulations and the project managers would enhance execution of waste management activities, such as regulating the waste disposal behavior, adopting better waste management plans, etc. Consequently, the amount of waste dumped illegally will be reduced due to the enhancement of CWM.

In the positive feedback loop R1, a change on any variable will affect itself in a reinforced way. For example, an increase in practitioners’ initiative to manage waste will contribute to the social performance of CWM, and the higher social performance of CWM will then increase the public satisfaction about waste management. Since nowadays the social impact has been an increasingly important aspect when assessing the feasibility of construction projects in China, major practitioners’ initiative to manage construction waste will to some extent be stimulated by greater public satisfaction about CWM. Therefore, in this feedback loop, an increase in practitioners’ initiative to manage waste will lead to an improvement in the public satisfaction about CWM.

Feedback loop R2 describes the interrelationships between “new job opportunities” and “conduct of waste management”. On one hand, the implementation of CWM provides more new job opportunities for the entire society; on the other hand, the employment of more people for CWM could in turn better facilitate the conduct of CWM activities.

In the positive feedback loop R3, it can be observed that the physical working condition will influence impacts of waste management activities on the long-term health of workers involved. Better physical working condition will make workers suffer fewer...
impacts on their long-term health. If the workers have to work under a worse condition that brings adverse impacts to their long-term health, the public satisfaction about waste management will be relatively lower. Then the public satisfaction will affect practitioners’ initiative to manage waste positively; that is, if the public satisfaction is greater, practitioners will be more willing to undertake waste management activities. The rise in practitioners’ initiative to manage waste will improve the social performance of CWM. Consequently, the higher social performance of CWM contributes to a better working condition for performing waste management.

Some of the causal loop relationships in feedback loop R4 are the same as in loop R3, the difference is that physical working condition will affect the safety of operatives in waste management, and then the safety of operatives will contribute to the public satisfaction about waste management. A change on any variable within this causal loop will influence itself in a positive way.

Finally, in feedback loop R5, the behavior of the feedback loop will be reinforced by a change on any variable. For example, an improvement in the safety of operatives will promote the public satisfaction about CWM, which then contributes to practitioners’ initiative to manage waste. Afterwards, a higher social performance of waste management will be achieved through the enhancement of practitioners’ initiative to manage waste. Finally, the higher social performance of CWM contributes to a better safety environment for operatives to execute waste management.

4. Stock-flow diagram

Having identified the major variables affecting the social performance of CWM, they have to be quantified and their interrelationships have to be defined mathematically. To this end, the conceptual model in Fig. 3 is converted into a stock-flow diagram by utilizing the iThink software, which is shown in Fig. 4. The stock-flow diagram is the formal model because through the converting process, many details which are essential to enable the model to be simulated quantitatively are added to the conceptual model. For the sake of understanding, all detailed descriptions of the variables quoted in the model are tabulated in Table 1.
5. Simulation results and analysis

5.1. Data collection

For quantitative simulation and analysis, all variables and feedback loops have to be firstly quantified, which is achieved in this study by collecting data from a real case in the construction industry of China. The studied case is a new frame-structured building which is located at Shenzhen city of South China. The building height is 44 m with nine stories above ground and one story underground. Data were mainly collected through two channels. One is via a series of formal and informal meetings, interviews and communication with five on-site staff (i.e. one project manager, one on-site manager, one on-site technical engineer and two supervisory engineers), each of whom has a wealth of experience in construction management, as well as a good understanding about CWM. The other is through interviews and consultation with eight neighboring inhabitants. The justification for involving the inhabitants in the neighborhood is due to that the assessment model is concerned with several variables associated with the social impact of CWM activities. It is noted that the perception from those who were affected by the inappropriately dumped construction waste is important for effective evaluation of the social performance of CWM. The other is through interviews and consultation with eight neighboring inhabitants. The justification for involving the inhabitants in the neighborhood is due to that the assessment model is concerned with several variables associated with the social impact of CWM activities. It is noted that the perception from those who were affected by the inappropriately dumped construction waste is important for effective evaluation of the social performance of CWM. But due to the great difficulty in obtaining related information from these people, their perception of the social impacts of illegal waste disposal is measured based on propositions of the eight inhabitants.

5.2. Validation of the SD model

Validation is an important process for building confidence in the model. Based on a critical review of tests applicable to SD modeling, Qudrat-Ullah and Seong (2010) suggested a group of tests that a SD model should go through, which are listed as follows:

- **Test 1 – boundary test:** whether the model contains all variables that are essential to the research problem?
- **Test 2 – structure verification:** whether the model structure is consistent with relevant descriptive knowledge of the system being modeled?
- **Test 3 – dimension consistency:** the model must be dimensionally valid, i.e. the dimensions (or unit of measurement) of the variables on the right-hand side of each equation should be able to be converted to the dimension of the variable on the left-hand side of the equation.
- **Test 4 – extreme conditions:** whether the model exhibits proper behavior when subjected to extreme conditions?

Qudrat-Ullah and Seong (2010) further argued that although these tests by no means are exhaustive but comprise the core of battery of tests for SD models. Therefore, these tests are applied to the SD model developed in this study for increasing its robustness and reliability. A blow-by-blow account of the validation process is provided in the following section.

Test 1: This test is concerned with whether the model contained all essential variables that correspond to the research purpose; meanwhile, the test helps assure variables that are irrelevant to the research question are excluded from the model. This test is performed by examining all the variables that have been embodied in the SD model as shown in Fig. 4. Ultimately, it is found that each of the variables is pivotal to the research purpose which is to assess the social performance of CWM.

Test 2: This test is to make sure that the structure of the model is logical and particularly is supported by collected data and/or existing literature. This structural validation is fulfilled by referring back to the causal loop as illustrated in Fig. 3. It can be seen obviously from the causal loop development process that all cause-and-effect chains depicted in the diagram are either gleaned from existing literature or based on acknowledged knowledge/perception.

Test 3: This test requires that measurement units of all the variables in the model are dimensionally consistent. Fortunately, the software iThink offers a useful function of dimension checking after measurement units of all the variables are determined. Hence, the model has been validated for dimension consistency.

Test 4: In this test, behavior of the model is examined under extreme conditions. Normally, extreme values are assigned to specific variables and then the generated behavior is compared to the real-system behavior as anticipated or understood. For illustration purpose, the variable PWE (physical working environment in CWM) is taken as an example herein for extreme condition tests. The main aim is to simulate how the value of AIPWE (Accumulated physical working environment in CWM) will change when extreme values are assigned to PWE. The testing results are illustrated in Fig. 5. In the model, the variable AIPWE can be affected by the

![Fig. 5. An example of extreme condition tests (curve 1: PWE = 0; curve 2: PWE = 70; curve 3: PWE = 100).](image-url)
variable PWE. They are all quantitative variables and thus based on a scale ranging from 0 to 100, with 0 indicating the worst physical working environment and lowest effect of physical working environment on the social performance of CWM, respectively, and 100 indicating the best physical working environment and highest effect of physical working environment on the social performance of CWM, respectively. In the test, three scenarios are examined, including scenario 1 (PWE = 0, this is an extreme condition test), scenario 2 (PWE = 70, this is the base run) and scenario 3 (PWE = 100, this is an extreme condition test). It can be seen from Fig. 5 that if the project suffers the worst physical working environment, AIPWE shows a steady decline pattern, eventually approaching a level around 44 (Curve 1). This is due to that bad physical working environment will affect the social performance of CWM, and if no measures are taken to improve it, the situation will worsen. In the base run (Curve 2), AIPWE still decreases throughout the examined period but apparently with a lower decreasing rate compared with Curve 1. This is because that the current situation of physical working environment is unsatisfactory and needs to be ameliorated. If the physical working environment is hypothesized to reach a level of 100 at the beginning of the project, AIPWE will remain (Curve 3), indicating that the contribution level of physical working environment to the social performance of CWM is ideal and will be unchanged during the whole project duration. In summary, it is observed that the behavior of AIPWE under the extreme conditions is in line with the anticipated behavior.

Based on the above tests, it is concluded that the established model can be trusted and used for further simulation and analysis.

5.3. Results of the base run

The model is simulated over a total period of 18 months, which corresponds to the total construction duration of the studied project. Detailed mathematical equations describing the values of variables and the causal relations between variables in the model are appended to the paper. Simulation results of the model are shown in Table 2 and Fig. 6. Table 2 lists weighted values of eight variables in terms of the social influence of CWM activities, which encompass WVpimw (weighted value of practitioners’ initiative to minimize construction waste), WVjo (weighted value of provision of job opportunities), WPVpwe (weighted performance value of physical working environment in CWM), WPVos (weighted performance value of operatives’ safety in CWM), WPVlh (weighted value of practitioners’ long-term health), WPVrvidsi (weighted performance value of regulating illegal construction waste disposal to improve city image), WPVps (weighted value of public satisfaction about waste management performance) and WPVpariwd (weighted performance value of public appeal for regulating illegal construction waste dumping). Since the total weight of the eight variables is 1 and each of them is assigned equally in this case, each of them obtains a weight of 1/8. Therefore, all the variables can range from –12.5 to 12.5 (100 x 1/8 = 12.5), with –12.5 indicating the highest negative social impact and 12.5 representing the highest positive social performance.

The results show that four variables, including WVpimw, WPVrvidsi, WPVps and WPVpariwd, receive positive values throughout the simulation period, indicating that in the project under study, “practitioners’ initiative to minimize waste”, “regulating illegal waste dumping”, “public satisfaction about waste management” and “public appeal for regulating illegal waste disposal” contribute positively to the society. Three variables, including WPVpwe, WVos and WPVlh, obtain negative values, demonstrating that “physical working environment in waste management”, “operatives’ safety” and “practitioners’ long-term health” need to be improved to reduce the adverse impacts of CWM activities on the society. Additionally, results of WVjo show that from the 4th to 18th month, CWM in the project contributes to the society by providing new job opportunities.

<table>
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<td>Simulation results of the base run.</td>
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Furthermore, the results also show clearly how SoPV varies dynamically over the project duration. SoPV is a variable for examining the social performance of CWM of the project investigated. It can range from $-100$ to $100$, with $-100$ indicating the highest negative impact that CWM activities would impose on the society and $100$ indicating the highest positive influence. The curve in Fig. 6 shows that the SoPV of the project is projected to present a ladder-type growth in the first 15 months, reaching a value of 14.26 at the end of the 15th month. Although it decreases gradually to 8.93 at the end of the project, it is worth highlighting that the social performance associated with CWM in the project has been improving.

5.4. Results of scenario analysis

Now that as found above, the three variables of “physical working environment in waste management (PWE)”, “operatives’ safety (OS)” and “practitioners’ long-term health (LH)” influence the social performance of CWM negatively during the simulation period, the scenario analysis is focused on investigating whether management measures involving these variables could positively contribute to the social performance of CWM. However, according to the model in Fig. 4, practitioners’ long-term health (LH) can only be affected by the social performance of CWM (SoPV). That is, if the social performance is effectively promoted, the impact of CWM activities on practitioners’ long-term health will be relieved. As a result, three scenarios encompassing variables of PWE and OS are designed, which are:

- **Scenario 1 (S1):** this scenario is concerned with whether an improvement in PWE (physical working environment) would enhance the social performance of CWM.
- **Scenario 2 (S2):** this scenario is to investigate whether an improvement in OS (operatives’ safety) would be helpful in promoting the social performance of CWM.
- **Scenario 3 (S3):** this scenario is to figure out whether improvements in both PWE and OS would enhance the social performance of CWM.

It is apparent that S1 and S2 are single-policy scenarios and S3 is a multi-policy scenario. Scenario 1 is performed by testing how changes in CPWE (changing of physical working environment) will influence the value of SoPV. CPWE is a variable to reflect the changing of physical working environment, and it is defined within an interval of $-5$ and $5$, with $-5$ indicating the highest decreasing rate and $5$ indicating the highest increasing rate. Scenario 2 is simulated through modeling how changes in CSO (changing of operatives’ safety) will affect the value of SoPV. CSO is a variable for measuring the changing of operatives’ safety environment. It is measured by a scale ranging from $-5$ and $5$, with $-5$ representing the highest worsening rate and $5$ representing the highest bettering rate. According to the model, values of CPWE and CSO are determined by PWE and OS respectively. Detailed values of CPWE and CSO assigned in each of the scenarios are tabulated in Table 3.

Simulation results of the three hypothesized scenarios are shown in Fig. 7. It can be seen clearly from Fig. 7a that promoting physical working environment will significantly improve the social performance of CWM. This is evident from the value of SoPV, increasing from 8.93 in the base run to 15.31 in Run 4 at the end of the simulation period. Among the three designed alternatives, the one resulting in Curve 4 (scenario S1-4) is of the most significance. The results indicate that in the studied project, management measures dedicated to bettering the physical working environment can gain substantial effects on promotion of the social performance of CWM.

Fig. 7b illustrates the simulation results when launching management measures associated with operatives’ safety. It can be by and large concluded that improving operatives’ safety can contribute greatly to enhancement of the social performance of CWM, which is proved by values of SoPV increasing from 8.93 in the base run to 14.46 in run 4 at the end of the project duration. However, it should be noted that in the first three runs, values of SoPV increase dramatically, while in the fourth run, only a slight increase in SoPV is perceived. This to a large extent implies that although improving the current safety climate of the investigated project can enhance the social performance of CWM, the best resultant effect is obtained before the level of operatives’ safety reaches the one resulting in Curve 3 (scenario S2-3). After that, the marginal utility for promotion of the social performance of CWM will decrease. These results suggest that the level of operatives’ safety represented by Curve 3 can be used to benchmark effects of management measures aiming at enhancing the social performance of CWM through changing operatives’ safety environment.

As mentioned above, scenario 3 comprises multiple management measures. Particularly, this scenario involves two alternatives (i.e. S1-4 and S2-3) that are most effective in improving the
Fig. 7. Simulation results of scenario analysis.
social performance of CWM. Fig. 7c exhibits simulation results of the base run and the run implementing the two alternatives simultaneously. It is obvious that after adopting the two alternatives, the value of SoPV reaches 20.41 at the end of the project duration, demonstrating a greater increase compared to those alternatives in scenario 1 and scenario 2. By comparing the two curves throughout the whole period, it can be noted that the social performance of CWM can be increased sharply from the 4th month onward after adopting the multi-policies. These results evidently demonstrate the potential of applying various management measures to increase the SoPV.

Although the above results provide valuable insights into management measures that can be potentially used to improve the social performance of CWM, it is worth highlighting that these scenarios simulated are by no means exhaustive and thus there are several other scenarios encompassing different management measures that can be devised and simulated by using the model. Nevertheless, the developed model can serve as a useful tool for experimenting effects of different management measures on the social performance of CWM.

## 6. Conclusions

Increasing research efforts have been dedicated to managing construction waste worldwide. Although it is known that construction waste can cause economic, environmental and social impacts in a number of ways, however, existing research has been primarily focusing on the economic performance of CWM while scant attention is given to investigation of its social performance. This study thus aims at evaluating the social performance of CWM by using a SD approach. Based on the work of this article, a model comprising six feedback loops is found to be useful for dynamically assessing the social performance of CWM.

Major variables affecting the social performance of CWM are identified; further, their underlying relationships are depicted through a causal loop diagram. This facilitates a better understanding of how various variables influence the social performance of CWM as a whole. After a series of essential validations, the established model is simulated by incorporating empirical data collected from a construction project in China. The findings show that the investigated project receives a value of 8.93 in the social performance of CWM eventually. Although the value is relatively low indicating a poor social performance, the dynamic results of SoPV throughout the simulation period demonstrate that the social performance of CWM in the project has been improving. Furthermore, the results also indicate that the poor social performance is largely attributable to "physical working environment in waste management", "operatives' safety" and "practitioners' long-term health". The results of scenario analyses suggest that scenarios comprising various management measures can significantly maximize the effect on promoting the social performance of CWM. Meanwhile, it also demonstrate the potential of the established model to be used as a tool for quantitatively simulating different management measures so that best measures to enhance the social performance of CWM can be identified.

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## Appendix A

Mathematical equations depicting the causal relations of variables in the model:

\[
\text{AERIWDI}(t) = \text{AERIWDI}(t - \text{dt}) + (\text{IIDSI}) \times \text{dt}
\]

INIT AERIWDI = 0

\[
\text{IIDSI} = \text{GRAPH}(\text{AERIWD})
\]

\[
\begin{align*}
(0.00, 5.00), (10.0, 3.95), (20.0, 3.18), (30.0, 2.48), (40.0, 2.00), \\
(50.0, 1.63), (60.0, 1.35), (70.0, 1.00), (80.0, 0.675), (90.0, 0.325), (100, 0.00)
\end{align*}
\]

\[
\text{AIPWE}(t) = \text{AIPWE}(t - \text{dt}) + (\text{CPWE}) \times \text{dt}
\]

INIT AIPWE = 80

\[
\text{CPWE} = \text{GRAPH}(\text{PWE})
\]

\[
\begin{align*}
(0.00, -2.00), (10.0, -2.00), (20.0, -2.00), (30.0, -2.00), (40.0, -2.00), \\
(50.0, -2.00), (60.0, -1.00), (70.0, -1.00), (80.0, 0.00), (90.0, 0.00), (100, 0.00)
\end{align*}
\]

\[
\text{ILH}(t) = \text{ILH}(t - \text{dt}) + (\text{ILH}) \times \text{dt}
\]

INIT ILH = 100

\[
\text{ILH} = \text{IF \ SoPV} < 0 \text{ THEN } -1 \text{ ELSE IF SoPV} \leq 20 \text{ and Month } < 12 \text{ THEN } -2.5 \text{ ELSE } -1.5
\]

\[
\text{OS2}(t) + \text{OS2}(t - \text{dt}) + (\text{CSO}) \times \text{dt}
\]

INIT OS2 = 100

\[
\text{CSO} = \text{GRAPH}(\text{OS})
\]
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