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A SYSTEM DYNAMICS-BASED ECONOMIC PERFORMANCE SIMULATION OF CONSTRUCTION WASTE REDUCTION MANAGEMENT: EFFECTIVE APPLICATION OF PREFABRICATION

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Abstract

Cost effective management of construction and demolition waste (C&DW) has become a serious issue with increased construction activity and modern urban lifestyle which is damaging environment, eating up resources and causing rapid land use changes. These factors have influenced the construction industry significantly and therefore gained the practitioners' attention in recent past. New strategies of C&DW reduction management are being devised and reported; this research aims at providing a better C&DW management technique which will benefit the construction industry in terms of waste reduction and consequent cost-benefit. The main focus of this research is restrained to prefabrication of construction material and its effects on economy of tall buildings. The data collected from traditional methods for CDW management and prefabrication factories is based on interviewed surveys from project managers, quantity surveyors and experienced site managers. The collected data is then processed into System dynamics using "VENSIM PLE" by creating causal relationships with dependent and independent variables. Economic theory in contrast with conventional and prefabrication methods of construction has been incorporated in this study. Results show that usage of prefabrication technique proves to be more economical in managing C&DW. Construction waste management through prefabrication technique shows a reduction of cost around 79% as compared to that in construction through conventional methods. This suggests that prefabrication technique can considerably reduce C&DW as well as costs for its management accordingly.

Key words: construction and demolition waste, economic performance, prefabrication, recycling, system dynamics

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1. Introduction

1.1. Background

Developing countries comprise construction activities due to which there is a large impact on environment as well as on economy. Construction industry generated major amount of solid waste therefore it is considered as one of humongous degrader of environment (Li et al., 2014; Migliore et al., 2018). Short term economic benefits are prioritized by construction participants and activities which are not environment friendly therefore better management is sought (Campos et al., 2016; Li et al., 2014). Waste management is generally considered to be the duty and responsibility of local establishments only (Ghinea and Gavrilescu, 2010; Vidanaarachchi et al., 2006). As the construction proceeds, large amount of construction waste such as concrete, mud, reinforced concrete and scrap are produced which need to be sorted (Simion et al., 2013; Yuan et al., 2013). Hong Kong produces 80% of concrete waste from construction industry (Baldwin et al., 2009). Construction waste can never be reduced to zero so for

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that purpose, several methods have been improvised by the engineers and practitioners to manage the construction waste to a minimal level possible (Ulubeyli et al., 2017). These methods include the 3R's theory (Reduce, recycle, reuse), landfilling, pre-casting and prefabrication. It has been reported that more than 50 % of the land filled materials comes from construction waste in United Kingdom (Ferguson, 1995) which amounted up to 70 million tons. Nearly 1 ton of solid waste is landfilled per person annually in Australia and 44% waste is of construction industry (Yuan, 2012). High landfilling requirements are causing shortage of available land in urban areas. Shenzhen in China is only left with 23 million m^3 space available for landfilling which could hardly fulfil the waste disposal needs for one more year (Ding and Xiao, 2014). One of the disposal options to reduce burden on landfill resources, is to reuse the C&DW for other purposes e.g. public filling. During 2000 in Hong Kong, on average 376970 tonnes of construction waste was generated out of which 80% was utilized for public filling areas for retrieval purposes and remaining 20% was landfilled, resulting in reduction of landfilling spaces (Baldwin et al., 2009). In Hong Kong during 2004, 34% of the free land space was consumed by landfills according to Tam and Hao (2014).

Due to rapid increase in C&DW generation and considering its environmental impact, its management is an emerging urban problem (Şchiopu et al., 2007; Wang et al., 2014). Construction waste is the mixture of inert materials such as steel, concrete, bricks (which are the major components of any construction) as well as non-inert materials such as plastics, polystyrenes, thermo polis, wood and chemical aggregates. A large amount of these materials are discarded as construction waste; such waste is abridged by the methods deliberated in the following section briefly (Poon et al., 2013). Several measures for management of C&DW have been adopted by different developing countries over the time. Hong Kong has limited space because of high rise trend, land is expensive even so the development rate is high, and therefore, a lot of C&DW waste is produced because of construction activities. Up to 70% of all construction waste is reused as filling material in Hong Kong, 12 to 15% is used for retrieval and concrete works whereas 15 to 18% is recycled or used in landfills (Jaillon et al., 2009). Government of Hong Kong has formulated and applied policies for construction waste management, such as (a) on site sorting, (b) ensuring the proper use of 3Rs by their policies and (c) the polluter has to pay fine. Studies show that Hong Kong has already achieved a generation target of 7 million USD through the disposal of C&DW materials in landfills (Jaillon et al., 2009). Chinese government launched a program which insisted upon sorting and use of 3Rs for four major materials in C&DW including metals, wood, concrete and bricks (Lu and Yuan, 2011). A study conducted in Thailand between 2002 and 2005 examined that over 1.1 million tons of C&DW was generated per year which constituted about 7.5 % of total amount of waste being dumped and landfilled (Kofoworola and Gheewala, 2009). Recycling is being promoted in Thailand since past few years as the construction waste increased over time. Its effective implementation improved economic and social benefits (Kofoworola and Gheewala, 2009).

Considering developed countries, though Canada has vast land space available for landfilling, its larger cities are facing challenges, managing their C&DW being dumped in landfills (Yeheyis et al., 2013). Scandinavian countries are using recycled C&D waste at high ratios. The leadership in energy and environmental design (LEED) has made standards for sustainability of construction projects all over Canada (Yeheyis et al., 2013). The Canada Green Building Council (CaGBC) aims at promoting green buildings and low resource consuming homes and communities throughout the country. The key rule of the CaGBC is to manage C&D waste by 3R's technique (Yeheyis et al., 2013). According to Ekanayake and Ofori (2004), proper planning and control over construction waste minimization is a major role in C&D waste reduction on site.

1.2. 3R's Theory

3R's refers to a comprehensive approach for solid waste management and it is an important approach regarding waste reduction to a minimum rate. It basically stands for (a) Reduce, (b) Reuse and (c) Recycle (Rogers, 2011; Yuan and Shen, 2011). The term reduce refers to all activities focused on reducing the waste by either using resource optimization or by comparatively less material (i.e. required amount of material). Reduction of C&DW helps in minimizing the generation of waste and increasing the possibility of reusing and recycling of C&DW management (Esin and Cosgun, 2007; Strufe, 2005). It is the controlling of waste generation before it is even processed such as sorting of waste that is generated on-site (Hong et al., 2010). In support of this, a study revealed that 0.3% of fresh concrete waste is generated in batching plants which can be reused after recycling in a controlled environment (Kazaz et al., 2018).

Reusing construction material means returning the material back in the construction process which was wasted after previous construction. Reusable materials can be found in traditional construction method as well as prefabrication for a better circular economy (Minunno et al., 2018). Reusing construction material has several advantages such as preservation of structure while consuming comparatively less time and energy for utility (Begum et al., 2006). Construction material wasted from large scale projects can be reused for small scale local projects. Reusing of construction waste material minimizes the need for manufacture of new material for construction. Reusing of replacement parts or entire components is possible in both, prefabricated construction as well as conventional construction (Minunno et al., 2018). However, it has been reported for prefabricated buildings that proportion of reused material in can be as high as 81% (Aye et al., 2012). It also reduces the amount of impracticable waste sent to the landfills for dumping (Bartlett et al., 2004; Mulder et al., 2007). Total waste generation from conventional construction was noted to be 94% from which 70% was recycled and reused in Malaysia (Begum et al., 2010).

Recycling construction material involves the extraction of useful items from the wasted material. It is the removal of parts from the stream and is used as base material in the manufacture of new material for construction (Ledesma et al., 2015). In the past few years, recycling of construction waste has been recognized as the most efficient method to reduce the construction waste. The construction sector is the largest user of resources which generates more construction waste. This waste can be reduced by recycling methods or reusing. Integration of scrap material, waste and by-products maybe recycled into new components in case of conventional methods of construction (Minunno et al., 2018). The recycling approach has been applied by the governmental bodies of Europe through rules and regulations and it has successfully reduced the construction waste (Pires et al., 2019).

1.3. Feasibility of prefabrication

Low waste construction methods can be a big step towards efficient management of C&D waste. Such technologies can be beneficial for reduction of waste which includes prefabrication, innovative form work, false work technologies and low waste structures (Jaillon et al., 2009). The best way of minimizing construction waste is not to let it generate initially and for that purpose prefabrication provides the remedy (Tam and Hao, 2014). It was revealed that waste reduction could be achieved if the use of pre fabrication is applied as compared to the conventional construction in Turkey (Esin and Cosgun, 2007). Japan prefabricated construction suppliers and manufacturers association was established in 1963 and since then the trend of prefabrication has increased (Zhang et al., 2018).

Adoption of prefabrication has been prioritized in Malaysia because of its construction waste reducing nature (Begum et al., 2010). Most of the high-rise residential buildings, if they adopt pre-casting and pre-fabrication techniques, can lessen the production of waste (Baldwin et al., 2008). It is also identified that conventional construction exceeds in concreting, steel works, plastering and finishing. Prefabrication material can be designed for better recycling and they also can be designed for maintenance during operational ages (Minunno et al., 2018). Wearing and tearing rate of a prefabricated concrete and steel can be reduced up to 20% as compared to traditional construction (Shen et al., 2019). However adoption of prefabrication for concreting can achieve a waste reduction of 90% when compared with conventional methods (Tam et al., 2007), up to 56% reduction of steel wastage and 60% of concrete waste reduction according to a study of Tam and Hao (2014). Another study reported 50% of the construction waste reduction when prefabrication technique was applied (Lu and Yuan, 2013) in Hong Kong. In another study, 52% of construction waste reduction by prefabrication was reported (Aye et al., 2012).

Prefabrication proves to be a better solution to tackle with the construction waste problems. As per previous studies, it is shown that using precast concrete results in generation of construction waste which is 10-20% lesser than that of conventional method of construction and C&DW management (Jaillon et al., 2009). Prefabricated buildings help in the recovery of prefabricated components during demolition process giving a better implementation of 3R's, these components can be reused as well as recycled (Couto et al., 2018). In a study of tall buildings, construction waste was noted to be reduced up to 13% roughly as well as consuming 9% less construction resources (Shen et al., 2019). According to Cao et al. (2015) consumption of resources are reduced up to 36% for prefabricated components and in case of prefabricated residential buildings resource consumption reduces up to 20%.

Prefabricated method reduces the complications produced in wet trade works, hence reducing the construction waste production (Li et al., 2014). There has been an evolution of a concept of lean thinking (Aziz and Hafez, 2013). This concept provided ideas of optimizing resources so that it mass benefits the economy and reduces waste. This process was introduced first in 1950's and worked its way up in 1990's to the implementation phase (Dineshkumar and Kathirvel, 2015). The concept increased the efficiency overall, quality and reduced the non-productive activities. Prefabrication is the process which revolves around the idea of lean thinking in the field of civil engineering and utilities. Organizations like "SKANSKA Inc." have applied the process of prefabrication to study the solid outcomes of the methodology (Wokas, 1964). Sustainability of economy is desired from a construction project therefore prefabrication provides that economy effective process (Mao et al., 2013). In 1998 prefabrication technique was adopted overall 8% and increased to 20% by 2010 in Hong Kong (Zhang et al., 2018). Another study of Lu and Yuan (2013) shows that 17% of structural members in Hong Kong were being produced in 2002 which increased to 65% by 2005.

The significance can be shown by the following example that technological innovations in prefabrication techniques are a result of sociocultural innovation. The quality of prefabricated product is firm and better as the process is executed in a quality-controlled environment i.e. prefabrication factories; adoption of prefabricating methodology is inevitable in the construction industry (Li et al., 2016). This mode has following advantages of its own: (a) lesser dependency on human resources when compared with the conventional method, (b) lesser or no use of formwork, (c) lesser managing requirements and (d) elimination of post concrete repairs (Li et al., 2016). Construction time reduces by 20% in prefabricated construction and 36% less resources are depleted (Zhang et al., 2018). 100% of construction waste can be reduced by applying prefabrication technique in plastering works (Tam and Hao, 2014). Off-site prefabrication only produces 2% or lower waste by weight however in on-site prefabrication total waste generation ranger from 4% to 9% (Lu and Yuan, 2013). Prefabrication reduces labor intensive activities, provides safer environment, construction process is speeded up, better finishing is achieved and overall 30% of manpower is decreased, thus increasing the economy of project (Baldwin et al., 2009).

Many construction companies see their future in prefabrication with the increasing awareness (Tam et al., 2007). The things to understand about prefabrication arise are "how much sustainability can be achieved through this method?", "what better outcomes it can provide as compared with the other methods of waste management?" and "how much economy can be generated by what feasible C&DW management method?". Therefore, this research aims at providing a better technique that is prefabrication to manage C&DW more efficiently especially for developing countries and hence, putting a better impact on economy of construction industry. This can be judged by the results and analysis in the following research.

1.4. Situation of C&DW and prefabrication in Pakistan

Construction, the second largest sector of Pakistan after agriculture, plays a critical role in the development of country's economy. More than 35% of the workforce is directly or indirectly associated with this sector (Farooqui and Ahmed, 2008; Maqsoom et al., 2019). Most of the projects in Pakistan suffer the risk and failure due to the poor project performance (Ahmad et al., 2018; Maqsoom et al., 2018). Most of the developing countries encourage the application of prefabrication technique for better management of C&DW in construction projects. However, prefabrication is still not very commonly applied technique in the construction sector of Pakistan because of the barriers associated with higher initial costs, inflexibility in design changes of components, time consumption in design phase of components and requirement of skilled labour for setup (Ansari et al., 2016). Also Pakistan is lacking prefabrication factories/setups, therefore the technique is being applied at a very small scale construction work usually for making smaller structural components such as pre-casted small slabs, pre-casted small beams and columns that are used in small scale construction projects (Memon et al., 2014). However, this initial cost for setup can be recovered if prefabrication technique is applied for C&DW management, as per previous studies which show that the costs being saved from managing construction waste through prefabrication are comparatively higher than the costs saved from traditional construction methods. This can prove to be more beneficial if prefabrication technique is applied on large scale projects for C&DW management. Other studies on developing countries also show that prefabrication technique is being encouraged of management of construction waste but it is yet not being promoted in the construction sector of Pakistan at a very large scale (Begum et al., 2010; Memon et al., 2014).

2. Methodology

2.1. System dynamics (SD)

System dynamics is a tool which is used for understanding the complex problems as well as visualizing and analysing dynamic feedback systems. It was introduced by professor Forrester in 1958 (Ding et al., 2016). The capability of SD is to examine the dynamics of a complex system, streamlining in collaboration with and interaction among elements (Yuan and Wang, 2014). It is able to analyse the feedback structures that are present in physical and abstract systems (Goodman, 1997). 'What -if' scenarios can be simulated as well as the policy tests (Richardson and Otto, 2008). SD is often used for calculations and comparisons between different scenarios over time following its provided structures and rules (Sukholthaman and Sharp, 2016) .

From the past few years, SD is being used in various fields such as economic, business, agriculture, construction etc. Researchers have assessed environmental performance and economy of C&DW disposal using SD (Marzouk and Azab, 2014). Strategic planning of construction waste in Hong Kong was made by Hao et al. (2007) on SD for the better understanding of complex information and their management for the practitioners. Solution of complex management hierarchies is also developed by SD (Shen et al., 2012). Studies have suggested that SD is of great importance in the field of construction to cope with complex inter-relationships and dynamics of C&DW management (Ding et al., 2016).

2.2. Economic theory in context with C&DW management

Economic theory in construction industry plays a vital role as this industry is considered to be one of the most resource consuming industries of a country. The significance of this theory in the dilemma of construction industry is that large scale projects cannot be analysed as a whole but various calculations and workloads are to be divided and analysed to find out the best outcomes, so for that purpose major mathematical calculations require input of economics thus economic theory is used (Hillebrandt, 2000).

Economic theory in context with C&DW management has been used to evaluate and analyse proper handling of construction sites and how much economic benefits can be taken from a construction project. Good waste management makes good economic and business sense as well as puts a good impression of site, production quality and increment in profits (Jain, 2012). Benefit-Cost analysis has been used in order to examine C&DW management in terms of cost savings (Begum et al., 2006). Benefit-Cost analysis can be mathematically expressed as given by Eq. (1):

$$Net\ Benefits = Total\ Benefits - Total\ Costs \quad (1)$$

Where total benefits mean the revenue being generated in terms of cost by reusing and recycling of construction waste e.g. selling of construction waste and incentives provided, total costs can be termed as costs being spent for waste management such as reusing and recycling as well as all the direct and indirect costs. From the previous statistics, studies show that the purchasing costs of reused and recycled materials are 25% lesser than original new materials (Begum et al., 2006).

2.3. Model development

The flow chart in Fig. 1 only shows a logical relationship of the involved factors. Fig. 1 shows that due to construction activities waste is generated, therefore, sorting of this waste is required. This sorting is carried out by landfilling, recycling and reusing of waste which are the traditional methods used in construction industry. The remaining waste is dumped legally or illegally. If the waste is dumped legally, a certain cost is to be paid to the managing authorities and also cost is paid for acquiring the land legally. If illegally, then no extra amount for land is to be paid. But if during construction activities, source reduction i.e. prefabrication technique is applied, the generation of waste is automatically reduced from its source of origination. The following analysis is done in order to generate economic benefits.

2.3.1. The causal-tree

System dynamics provide tools such as causal mapping which are further subdivided into (a) causal tree and (b) causal-loops (Sweeney and Sterman, 2000).The causal loop in SD shows the major logic of the flow of variables. It shows the dependencies of all the variables upon each other. The dynamic behaviour of the model is assessed by causal loop diagrams (Lu and Yuan, 2011). Similarly, the current research generates a causal tree diagram which shows the dependencies of involved variables to influence the final variable that is supposed to be the outcome 'TCM' (Total cost for management). The causal tree shows the logical dependencies of different factors involved in the working of stock flow diagram. It basically defines the mechanism of the logic involved in the working of model.

Considering a phase of model development, four causal branches of the causal tree are analysed in which the different branches have different effect on the accumulation of costs. B-1 and B-2 provide positive feedback, B-3 and B-4 provide semi negative feedback (Fig. 2). Considering B-1, an increase in any variable within the causal tree branch will affect positively, e.g. 'CMR' is increased 'AWD' will increase automatically increasing the Total cost for management (TCM). Similar is the case with B-2. Regarding B-3; some variables put in a positive effect and some put in a negative effect. e.g., if 'CMR' is increased, it will affect positively on 'AWR' and if 'RUF' is increased, it will impact negatively on 'AWR' and hence on 'TCM' accordingly. Similar is the case with B-4.

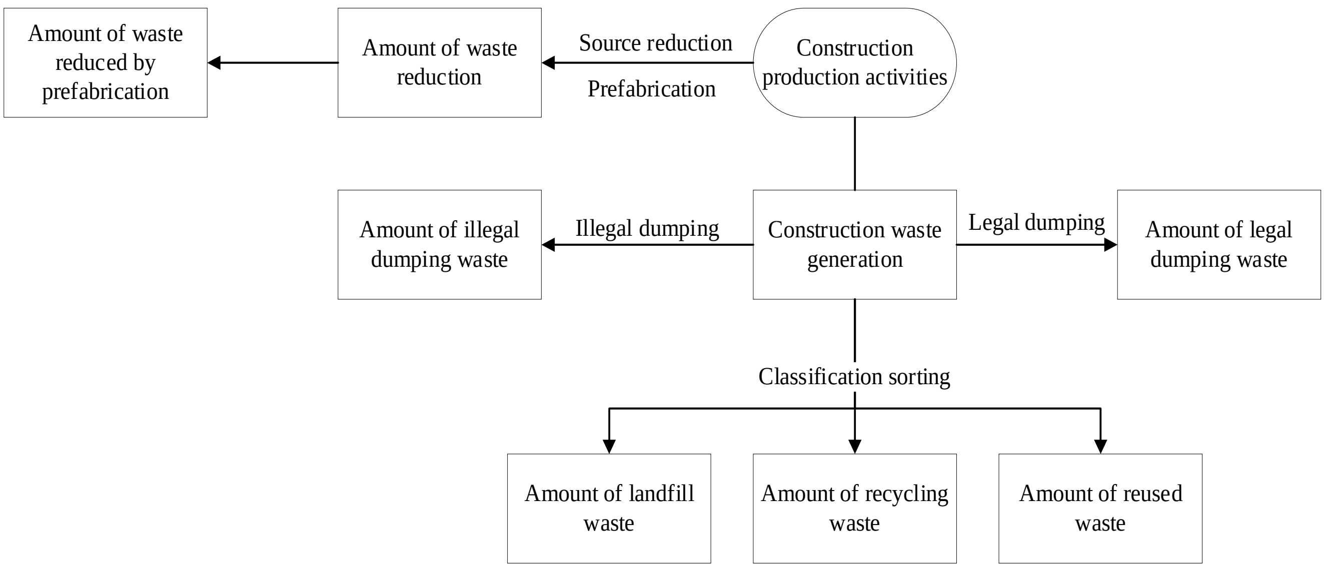

Fig. 1. The process of C&DW management (adapted from Ding et al., 2016)

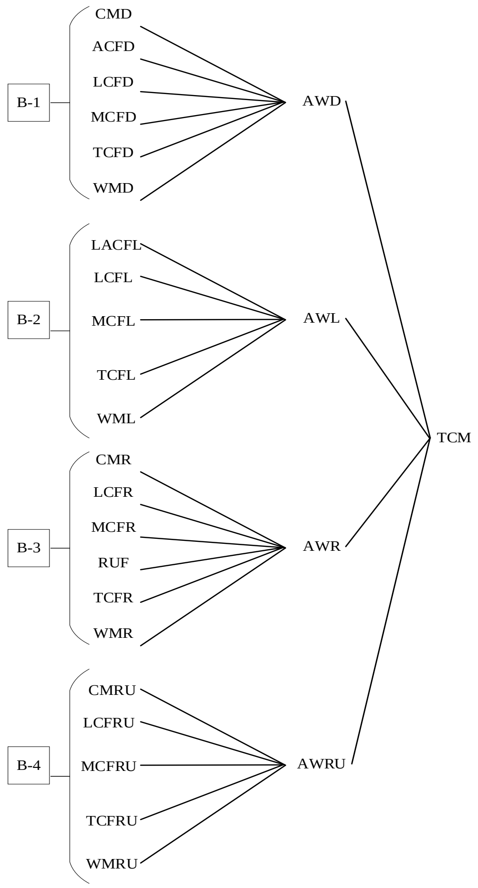

Fig. 2. The causal tree diagram (framework)

Before moving to the next step, it is difficult to explain the complete assumptions for simulation of the stock flow diagram; thus the main assumptions taken are; (i) Cost related variables show the direct relation with economic theory, (ii) CW managed with each technique is handled separately but ultimately accumulates at a single variable which gives the overall processing cost and (iii) There are two techniques which are compared after separate simulations but with same model inserting the values hypothetically for prefabrication technique and realistic values for the conventional method of construction.

2.3.2. Stock-flow diagram

From the causal tree diagram, all the main variables are identified. This causal tree is then converted into stock-flow diagram using VENSIM software which is shown in Fig 3. Abbreviations of the variables are described in Appendix A.

2.4. Model simulation

The data collected for the project to construct the model is through interviews which is the type quantitative analysis. For quantitative analysis, values are required to be assigned to the variables (Shen et al., 2012). To ensure the validation of variables involved in the model, interviews have been conducted at the constructed project site in Islamabad, Pakistan. The project is actually a commercial high rise building of total covered area 353,031 sq. m. The building comprises 23 floors with 2 underground levels. The construction actual data was collected over the time span of 3 years i.e. from 2008-2011. The data is analysed by combining interviewed values with literature data and local empirical data. Some of the variables have constant values throughout e.g. land costs, labour costs and transportation costs have fixed parameters which were interviewed by local authorities.

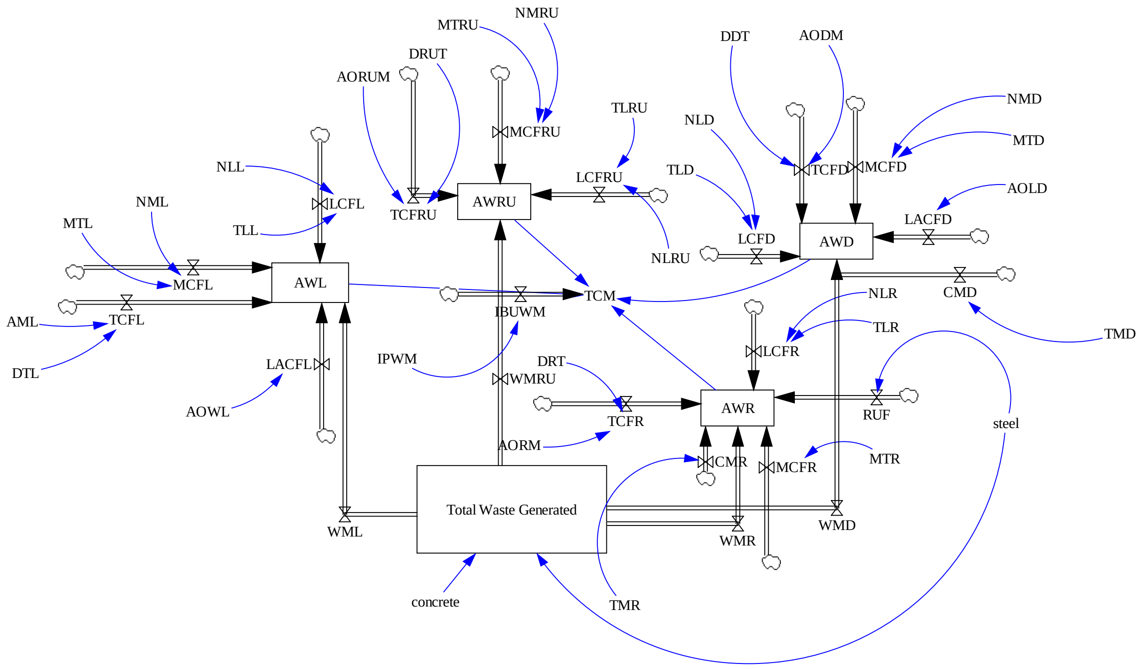

Fig. 3. Stock flow diagram of the model

The data for some variables was inserted by importing text files (notepad files) having '.dat' format in 'VENSIM PLE'. The values have been generated on the graph from these '.dat' files e.g. steel and concrete.

An example of importing of file and its result has been shown in Fig. 4 and Fig. 5, respectively. The authorities provided that all the concrete was dumped in the nearby vicinity of 10-15 km radius. Data was collected from the building authorities during the interview sessions of 15 days. The development authorities of city were also interviewed during the sessions jointly and it was provided that the land cost for dumping was 300 Rs./m^3 and a total of 40 m^2 was required per month for the traditional method construction waste management. For pre-fab method of construction, it was found that the authorities of that industrial area required no such land cost for dumping of material. Transportation cost for dumping of material was 0.0714 Rs./m^4. Three labours for loading of dumping material to the transport vehicle were required monthly at the wages of 500 Rs./day/person.

	steel
0	11
1	10.5
2	11
3	10.2
4	10
5	10
6	9
7	2
8	2.6
9	4.8
10	4.5
11	5
12	4.7
13	4.5
14	6
15	5.5
16	5.7
17	6
18	6.7
19	7
20	8
21	8.64
22	9
23	15.5

Fig. 4. '.dat' file data of steel

2.5. Model validation

Before simulating the SD model its validity is very necessary to check through a series of test. The model needs to reflect a proper meaning, it is designed for (Richardson and Pugh III, 1981). There are 5 tests used to check the validity of SD model (Ding et al., 2016). After applying all these tests, the SD model is considered to be valid regarding the proposed problem.

2.5.1. Boundary-adequacy test

This test fulfils three determinations: (1) Does a significant change occur when the boundary values are relaxed in the model behaviour? (2) Does the policy reference change when the boundary values are extended? (3) Is the problem relatable with the model? (Ding et al., 2016).

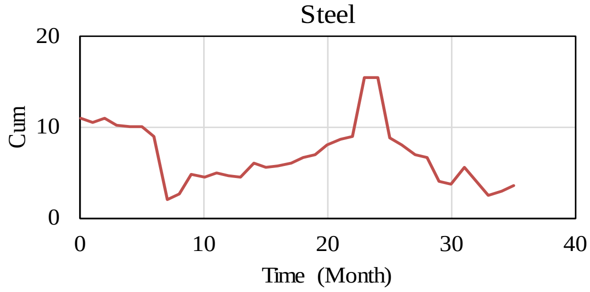

Fig. 5. Graph generated by inserting Fig. 4 values

2.5.2. Structure verification test

This test is done in order to test the consistency of SD model so that, the knowledge required to convey is actually being modelled in the system (Marzouk and Azab, 2014)Also the cause and effect chains are based on the literature and data involved in the research or not. Therefore, the structure verification test shows the actual system and logic of the problem (Ding et al., 2016).

2.5.3. Dimension consistency test

This test is done in order to check whether the equations involved in the SD model are dimensionally consistent or not (Sweeney and Sterman, 2000). VENSIM has a feature to detect any error in the equation when it is found inconsistent with the dimensions (Ding et al., 2016).

2.5.4. Parameter verification test

This test is done in order to check whether the parameters are consistent with numerical knowledge of the system (Ding et al., 2016). The parameter values for research are taken from previous literature data and interviews.

2.5.5. Extreme condition test

This test is done in order to check whether the equation is reliable even if extreme values are given to the model (Sweeney and Sterman, 2000). For example, if the values of total waste generated are taken to the extreme i.e. 1000 cum/month, 500 cum/month and 352.1 cum/month, then the values obtained are shown in Fig. 6. At 352.11 that is the realistic value and the result obtained is 218.85M rupees for TCM. At 500 cum/month the value of TCM obtained is 309.56M rupees. At 1000 cum/month TCM turns out to be 619.12M rupees (Table 1). After applying all the recommended tests, the SD model was found to be valid and relatable to the proposed problem.

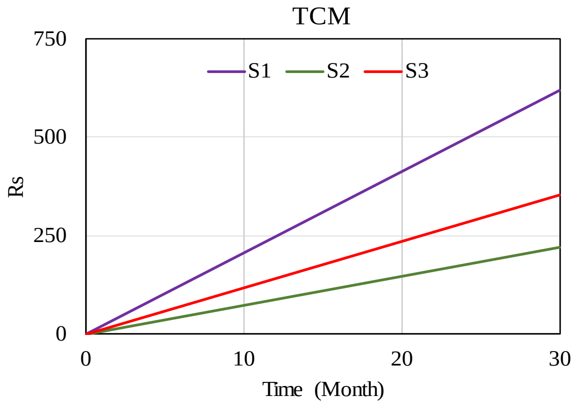

Fig. 6. Extreme condition test results

Table 1. Extreme values test results

Test no.	***Test value (cum/month)***	***TCM value (million Rs.)***
Test 1	352.11	218.85
Test 2	500	309.56
Test 3	1000	619.12

3. Results and discussions

After the input of all variables into the SD model, the economy of CW reduction is evaluated using 'VENSIM' over the time period of 36 months. The simulation results are analysed in the following section in detail: -

3.1. Scenario analysis

This section shows the results of waste management techniques and the cost spent for the waste reduction; referring to Fig. 7,the trend in the graph shows the amount of cost spent for construction waste reduction by 'AWD' in terms of cost as the waste is managed over the time period of 36 months by different scenarios. Similarly, Fig 8 shows the trend for 'AWR', Fig. 9 displays the trend for 'AWRU' and Fig. 10, depicts the trend for 'AWL'. Simulation is done by creating three scenarios that are simulating the model using the realistic values from conventional methods, applying hypothetical simulation for prefabrication method of reduction with values interviewed from the prefabrication plant and simulating by using average values from the previous literature and researches.

Scenario 1 is concerned with the use of traditional method of construction and the cost for managing the realistic construction waste produced during construction.

Scenario 2 is concerned with the use of prefabrication method of construction and the waste produced during the process of construction.

Scenario 3 is concerned with the values from previous literature and researches in the view of waste generated on the average for conventional method of construction.

3.2 Simulation results and discussions

3.2.1 Simulation results of AWD

In relation to the three scenarios, the results of AWD are presented in Fig 7. 'S1' shows that the total cost that is spent on dumping the waste by traditional method of construction is 131.3M rupees whereas 'S2' shows a value of 93.82 M rupees when prefabrication technique is applied, 'S3' shows the value substituted from previous literature and researches that is if average percentage of amount of waste dumped is applied on the research, the result obtained is 131.3 M rupees. Values entered to generate AWD results for the three scenarios are shown in Table 2 and Table 3.

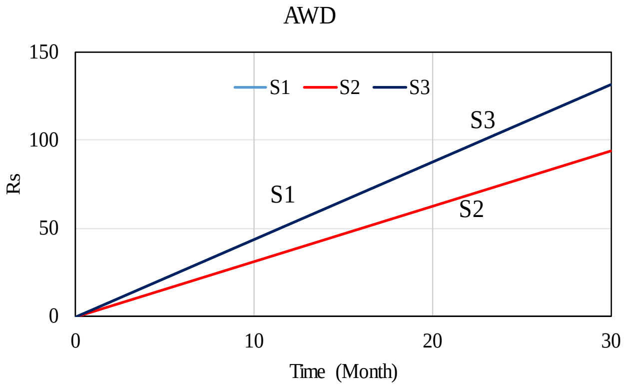

Fig. 7. AWD results of S1,S2,S3

3.2.1 Simulation results of AWR

Fig. 8 shows the results for 'AWR'. Cost for recycling the waste is 81.4 M rupees for conventional method of construction in 'S1' whereas, 'S2' shows a value of 33.5 M rupees also, 'S3' shows the substituted average value from previous researches and literature which gives a total value of 92.47 M rupees. Values of dependant variables for S1, S3 and S2 results are given in Table 4 and Table 5**.**

Table 2. AWD dependant variable values for S1 and S3

S No.	***Variables/Factors***	***Unit Quantity***	***Units***	***Sources***
1	CMD	7200	Rs./m^3	Interviews
2	LACFD	300	Rs./m^2	Interviews
3	LCFD	500	Rs./person.day	Interviews
4	MCFD	N/A	N/A	N/A
5	TCFD	0.0714	Rs./m^4	Interviews
6	WMD	98.08	%	Interviews

Table 3. AWD dependant variable values for S2

S No.	Variables/Factors	Unit Quantity	Units	Source
1	CMD	7200	Rs. /m^3	Interviews
2	LACFD	N/A	N/A	N/A
3	LCFD	550	Rs./person.day	Interviews
4	MCFD	N/A	N/A	N/A
5	TCFD	1.044	Rs./m^4	Interviews
6	WMD	95.669	%	Interviews

3.2.2 Simulation results of AWRU and AWL

Fig. 9 shows that there is no reusing of material in conventional method of construction 'S1', therefore, the graph shows a constant zero, in 'S2' a negative value of 'AWRU' is obtained which shows a return of 82.27 M rupees when prefabrication technique is implied whereas 'S3' shows a constant zero for there have been no reusing process. The variation is generated by entering the values given in Table 6. Fig. 10, shows the total cost for 'AWL' and no landfilling process has occurred for 'S1', so the graph shows a zero value constantly, similarly for 'S2' and 'S3' the graph shows a constant zero.

Referring to Fig. 9, the negative proceeding of the line S2 shows the return of cost from reused steel, therefore, the trend is negative and the negative value of 80M rupees shows that the cost returned by reusing the construction waste material is a positive effect on economy of project. S3 in Fig. 7, 8, 9, 10 shows the average values substituted for tests to compare the economy of all the three scenarios; values of steel and concrete in S3 have fixed percentages taken from previous researches and literature (Shen et al., 2000).

'RUF' in the stock-flow diagram shows the return percentage of the steel cost from recycling it or selling it. In Pakistan, the average return factor for steel is 40% of the actual cost of steel as shown in Fig. 11 substituted into the project values**.**

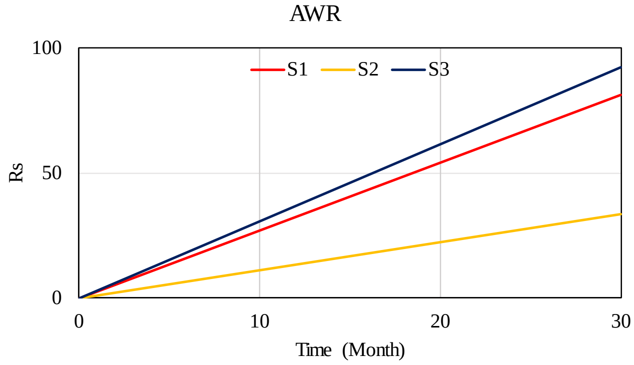

Fig. 8. AWR results of S1,S2,S3

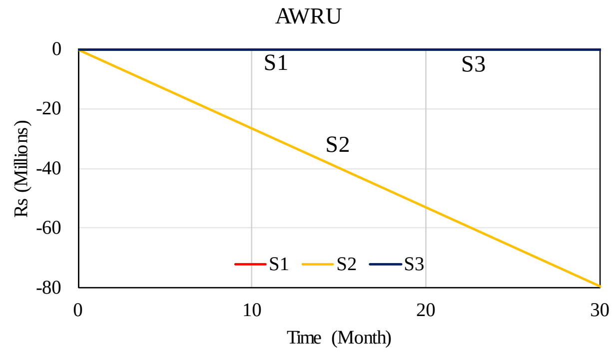

Fig. 9. AWRU results of S1,S2,S3

Table 4. AWR dependant variable values for S1 and S3

S No.	Variables/Factors	Unit quantity	Units	Source
1	CMR	565200	Rs./m^3	Interviews
2	LCFR	500	Rs./person.day	Interviews
3	MCFR	N/A	N/A	N/A
4	RUF	219800	Rs./m^3	Interviews
5	TCFR	N/A	N/A	N/A
6	WMR	1.91	%	Interviews

Table 5. AWR dependant variable values for S2

S No.	Variables/Factors	Unit quantity	Units	Source
1	CMR	565200	Rs./m^3	Interviews
2	LCFR	550	Rs./person.day	Interviews
3	MCFR	N/A	N/A	N/A
4	RUF	219800	Rs./m^3	Interviews
5	TCFR	N/A	N/A	N/A
6	WMR	1.732	%	Interviews

Table 6. AWRU dependant variable values for S2

S No.	*Variables/Factors*	*Unit quantity*	*Units*	*Source*
1	LCFRU	550	Rs./person.day	Interviews
2	MCFRU	N/A	N/A	N/A
3	TCFRU	N/A	N/A	N/A
4	WMRU	2.59	%	Interviews
5	CMRU	565200	Rs./cum	Interviews

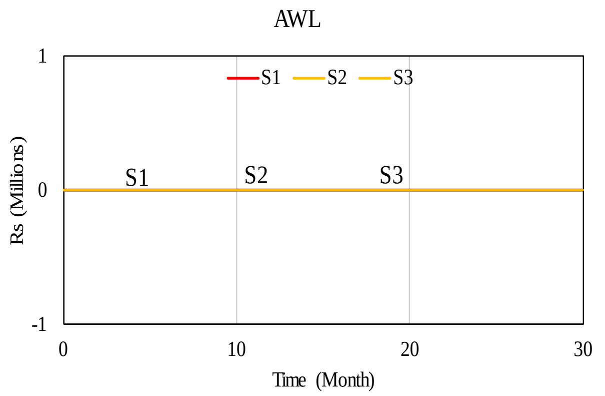

Fig. 10. AWL results of S1,S2,S3

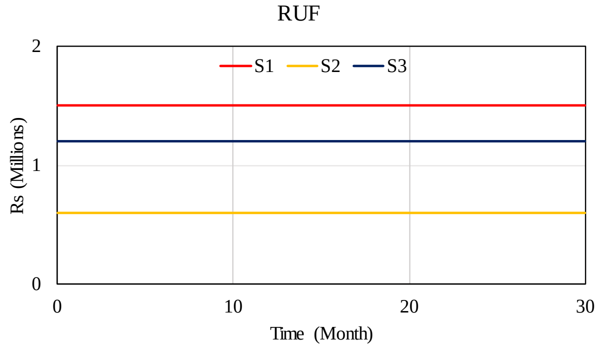

Fig. 11. RUF results for S1,S2,S2

3.2.4. Simulation results for TCM

Fig. 12, shows the final accumulated costs for C&DW management i.e. TCM, from the statistics and graph; S1 gives the total cost for management of C&DW is 218.85 M rupees which is near to S3, the global averages of construction waste production which are taken from previous studies which give a value of 223.7 M rupees. S2 shows the lowest incremental trend in the graph and give the accumulative cost of 45.07 M rupees. Table 7 shows the total costs for C&DW management in three scenarios from which the comparison can be clearly seen.

Table 8 shows the percentage values of construction material wastages taken from interviews from experts as well as previous researches. The value for 'S1' is generated by inserting the interviewed values taken from the project site, the value for 'S2' is generated by applying the construction waste percentages from prefabrication plant hypothetically on the actual data from the project under consideration whereas value of 'S3' is generated by hypothetically applying the percentages of construction waste from previous studies on the actual resources data of the considered project.

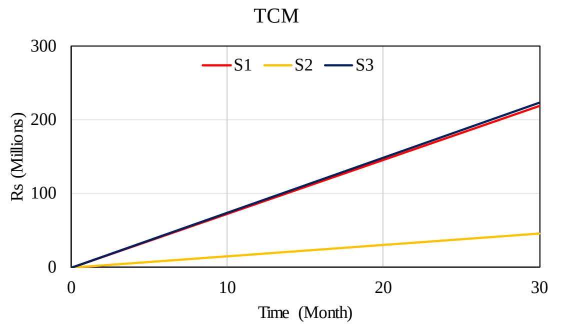

Fig. 12. TCM results for S1,S2,S3

Table 7. TCM result vales for S1,S2,S3

Scenarios	*TCM values (million rupees)*
Scenario 1 (S1)	218.85
Scenario 2 (S2)	45.07
Scenario 3 (S3)	223.7

These values for all levels (AWD, AWR, AWL, AWRU) are generated with the same method discussed in section 3.1. AWD gives a total value of 131.3 M rupees when waste is managed through conventional method, AWD for S2 gives 93.82 M rupees because the waste production level is very low, if prefabrication technique is adopted in construction; thus, waste management costs will be less. Similar is the case regarding AWR, AWL and AWRU. 52% of cost savings were found for prefabricated buildings when compared with traditionally constructed buildings for C&DW management (Aye et al., 2012). In case of pre-casted floor slabs up to 45% savings were achieved for concreting and up to 65% for steel (Baldwin et al., 2009). Construction waste management cost was reduced by 69% according to a study of Zhang et al. (2018). According to a study of Cao et al. (2015) the prefabricated residential buildings saved up to 25% to 80% of waste management cost as compared to that of traditionally constructed residential buildings. Usage of off-site prefabricated components can reduce cost from 70% to 100% hence decreasing the waste management cost on-site (Lu and Yuan, 2013). Tam et al. (2007) found that 84.7% of the total cost for C&DW management can be saved by adopting prefabrication technique similarly the above analysed results in this research after application of prefabrication hypothetically show that a total cost of 79.4% can be saved. Relating to economic theory, it is clearly seen that S2 is more economical than S1 and S3; S3 is most costly. The cost analysed above might vary for other researches according to the location, for example, the labour cost varies from place to place, and some places might have lack of resources, lack of skilled labour, variation in terrains and geographical features of land. Therefore, these factors might add some extra costs in total cost of management. Hence regarding benefits, it is found S2>S1>S3. The cost for S3 might seem awkward even with less percentages of waste generated as compared to S1 but it is because of less rate of return from steel recycling and with the same number of labours and machinery which the project had hired for S1.

Table 8. Waste values for scenarios

Description	*Value*	*Units*	*Sources*
Concrete waste for S3	4.96	%	Shen et al. (2000)
Reinforcement waste for S3	3.94	%	Shen et al. (2000)
Concrete waste for S2	2.95	%	Interviews
Reinforcement waste for S2	4.9	%	Interviwes
Concrete waste for S1	7	%	Interviews
Reinforcement waste for S1	5	%	Interviews

4. Conclusions and implications

The study shows that prefabrication technique proves to be the better C&DW management technique. From the statistical analysis of the three scenarios in the research, there is a prominent difference in the costs for construction waste management as clearly seen to be 79.4% as compared to conventional method for C&DW management. If proper incentives are provided for the construction waste management and prefabrication technique is adopted in construction projects, the economy of a construction project can be increased as desired by all construction participants.

This study can influence developing countries to a great extent in construction sector towards adopting the proposed technique. Using prefabrication technique in project means less production of construction waste therefore less construction waste to be landfilled and less budget needed to manage it, thereby increasing environmental efficiency as well. However, the mechanical properties for prefabricated structures are still in question and yet to be tested through engineering point of view.

Properties such as strengths, shear and bending properties, tension and compression, durability of prefabricated structural members still need to be tested. Though this might be the first time that economic theory and system dynamics are used in combination for construction waste management problems so it could provide a better gateway for future researches on this sector.

This research suggests a better framework for government bodies and construction firms to manage the construction waste efficiently and generate economic productivity. However, government of Pakistan (and other developing countries) needs to provide proper incentives for C&DW management through prefabrication to promote this technique in construction industry.

A monitoring body can be established for overlooking prefabrication works as done by Japanese prefabricated construction suppliers and manufacturers association (JPA) established by Japan. Currently, the government of Pakistan has aimed to construct 5 million low-cost houses in the next 5 years, so in order to provide economical housing with a better infrastructure and environment friendly project the government may opt prefabrication technique for construction waste management. The government may find guidelines in this research, as prefabrication can come up with a better solution for waste management, quality of product and less resource consumption; resulting in higher economy of the project.

This research focuses only on the economic performance of construction waste management in Pakistan. This research could not test the environmental performance simulation of construction waste reduction through the application of prefabrication; therefore, scholars may work on this gap. Further, only high-rise commercial building has been considered for this research where steel and concrete waste was taken as major entities for simulation. Other buildings apart from high rise buildings can also be studied with the same scenarios but different proportions of construction waste production according to the scale of projects hence more voids maybe covered.

Appendix A

No.	*Variable*	*Abbreviation*
1	AWR	Amount of waste recycling cost
2	MCFR	Machinery cost for recycling
3	LCFR	Labour cost for recycling
4	TCFR	Transportation cost for recycling
5	MTR	Machinery time for recycling
6	TLR	One labour time for recycling
7	NLR	No. of labours for recycling
8	DRT	Distance travelled for recycling
9	AOWR	Amount of recycling waste to be transported to recycling site
10	AWD	Amount of waste dumping cost
11	LACFD	Total land cost for dumping
12	MCFD	Machinery cost for dumping
13	LCFD	Labour cost for dumping
14	TCFD	Transportation cost for dumping
15	AOLD	Plot area for dumping
16	MTD	Machinery time used for dumping
17	DDT	Distance travelled for dumping
18	AODM	Amount of waste to be transported to dumping site

19	NLD	No. of labours used in dumping process
20	TLD	Time of one labour for dumping
21	AWRU	Amount of waste reusing cost
22	LCFRU	Labour cost for reusing
23	MCFRU	Machinery cost for reusing
24	TCFRU	Transportation cost for reusing
25	NLRU	No. of labours for reusing
26	TLRU	Time of one labour for reusing
27	MTRU	Machinery time for reusing
28	DRUT	Distance travelled to reuse processing site
29	AORUM	Amount of waste to be transported to reuse processing site
30	AWL	Amount of waste land-filling cost
31	LACFL	Land cost for land filling
32	LCFL	Labour cost for land filling
33	MCFL	Machine cost for land filling
34	TCFL	Transportation cost for land filling
35	AOWL	Amount of waste to be transported to land filling site
36	NLL	No. of labour used for land filling
37	TLL	Time of one labour for land filling
38	MTL	Machinery time for land filling
39	AML	Amount of waste to be transported to land filling site
40	DTL	Distance to the land filling site
41	TCM	Total cost of waste managed
42	TWG	Total waste generated
43	WML	Waste managing by land-filling
44	WMR	Waste managing by recycling
45	WMRU	Waste managing by reusing
46	WMD	Waste managing by dumping
47	NMRU	Number of machines used for reusing
48	NML	Number of machines used for land-filling
49	NMD	Number of machines used for dumping
50	IPWM	Incentives being provided for cost management
51	IBUWM	Incentives being used for waste management
52	RUF	Return cost for wasted steel
53	CML	Cost of material put in land-filling
54	CMR	Cost of material put in recycling process
55	CMRU	Cost of material put in Reusing process
56	CMD	Cost of material which was dumped
57	TMD	Total material dumped
58	TMR	Total material recycled
59	TMRU	Total material reused
60	TML	Total material land-filled

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