Research Journal of Applied Sciences, Engineering and Technology 8(11): 1312-1318, 2014
DOI:10.19026/rjaset.8.1101
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: April 26, 2014 Accepted: July 19, 2014 Published: September 20, 2014

Research Article

Construction Material Waste: Recognition and Analysis

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Abstract: This study was motivated by long term observations of the construction industry in the Northern region of the Kingdom of Saudi Arabia (KSA). The observations showed that the construction waste is becoming a serious environmental, economical and safety issue that affects the suburbs of the KSA. The study utilizes Likert scaled responses through a two-part questionnaire distributed to 42 contractors located in the Northern region of KSA. The first part of the questionnaire aims at identifying causes of material waste in building construction projects from the contractors' viewpoint. The second part seeks to rank the considered materials according to their level of importance from the contractors' viewpoint. The collected data was analyzed through Minitab statistical software. It was found that the most significant factors causing construction waste are: (1) inaccuracy in quantity surveys leading to over-ordering or under-ordering; (2) the selection of low quality products; (3) detail errors in design and construction; (4) the order of supplies in loose form; (5) and the inefficiency in resource management. The results of this study show that construction material handling and managerial decisions have a critical impact on the cause and effect of the level of construction waste. The study findings demonstrate that the most important benefits for considering construction waste are to know the exact required quantities for a construction project and to plan and prepare an accurate schedule for material arriving supply. The study recommends employing Lean Manufacturing principles to eliminate the construction waste and to enhance the decision making process in construction management in the northern part of KSA.

Keywords: Contractors, construction management, construction materials, materials waste, ranking, waste

INTRODUCTION

According to Construction Week, an online journal, the construction industry is one of the most important industries worldwide in terms of the invested capital expended, the number of workers engaged, in addition to being one of the major capital sources to any country. Statistics show that the KSA represents the largest project market in the Middle East in terms of the value contacts awarded in 2012 and future projects in the pipeline (www.constructionweekonline.com). The construction industry in KSA has experienced a huge boom during the last thirty years partially because of the wealth created by oil industries. This has lead to simultaneously an economic rapid development and a further need for infrastructure and expansion of cities (Lores, 1997).

Today, the construction industry is still growing, but at a slower pace in comparison to 30 years ago (Formoso *et al*., 2002). Among the drawbacks of this construction boom is the huge number of non value added activities such as construction material waste which negatively impact the environment, cause huge financial losses and create serious safety concerns. Unlike other types of industries, the final product of the construction industry is manufactured and assembled at the same place. Each item is unique and requires a proper management related to coordination, progress and quality control. The mobilization of construction knowledge and experience at the early phases of the project results in maximizing benefits. According to Lores (1997) "It has been shown that the integration of construction knowledge during the planning, design and procurement phases of a project bring extraordinary benefits into the delivery of the project. This is due to the fact that these are the phases in which one is able to influence the overall project the most".

This study is conducted in the northern part of Saudi Arabia to highlight the construction material waste, identification, relevance and causes from contractors' perspective through a questionnaire survey. It is hoped that the results of this study will help in minimizing the material waste in construction projects in Saudi Arabia and other countries.

Research needs: During the past decade, a number of major cities in KSA struggled during the rainy season because of flood. Huge damage to highways, roads and buildings occurred because of the lack of proper drainage sewage system and the random infrastructure.

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As a result, the Ministry of Municipal and Rural Affairs initiated a long term plan to remodel the current infrastructure, build new infrastructure, remold the old rural building mega housing complex and construct new roads and traffics to sustain the weather changes in the Kingdom. Such major projects and inhabitants will produce waste requiring the latest in recycling and waste management techniques to be employed. Yet, this multi-billion dollar sector continues to be under-developed and holds substantial business opportunities for the serious investor.

Previous work: Recognizing construction material waste is important not only from the perspective of efficiency, but also for the adverse effect it has on the environment (Formoso *et al*., 2002). Many construction firms generate high levels of material waste (Ekanayake and Ofori, 2000). The construction industry has a major impact on the environment, both in terms of the resources it consumes and the waste it produces. The construction industry is responsible for producing a variety of different wastes, the amount and type of which depends on factors such as the stage of construction, type of construction, performance and practices on site (Jones and Greenwood, 2001). To better understand how to deal with construction waste, it is very important to identify the waste. Ohno (1988) the co-developer of Toyota Production System (TPS), defined MUDA, the Japanese word for waste, as any non value added activity in manufacturing processing and production. Ohno (1988) identified the following seven types of waste:

- **Inventory:** Having more than the minimum stocks necessary for a precisely controlled pull system. In construction, this type of waste takes the form of extra material stocks, early delivery, a huge storage space which leads to delay and cause costly idle time for other resources.
- **Overproduction:** Producing ahead of what's actually needed by the next process or customer. In construction, this type of waste occurs when building ahead of demand per time.
- **Conveyance:** Moving parts and products unnecessarily, such as from a processing step to a warehouse to a subsequent processing step when the second step instead could be located immediately adjacent to the first step. In construction, this type of waste occurs as a result of unnecessary transport and multi-handling,
- **Processing:** Performing unnecessary or incorrect processing, typically from poor tool or product design. In construction, this type of waste occurs as a result of over design, unnecessary processing steps, low efficiency machines, inadequate size machines and over factoring.
- **Waiting:** Operators standing idle as machines cycle, equipment fails, needed parts fail to arrive, etc. In construction, this type of waste occurs when people stand idle waiting for information or material to arrive, or waiting for unfinished and late tasks.
- **Motion:** Operators making movements that are straining or unnecessary, such as looking for parts, tools, documents, etc. In construction, this type of waste results from unnecessary motion such as bending, reaching and moving between material stack and installation and construction area.
- **Correction:** Inspection, rework and scrap. In construction, this type of waste results from building defective parts or sections, using wrong materials, over/under estimation of the ratios in mixed quantities.

Another type of waste was added and defined by James Womack who considered unutilized skills and talents as a source of waste which has to be eliminated through elevating the level of individual workers productivity and efficiency through task scheduling and planning. In construction, this type of waste occurs because of untapped human potential, inadequate employment and unbalanced human resources allocations.

The elimination of waste has been largely used as a driver for improvement in companies that have adopted the Lean Production philosophy. Several studies from different countries have confirmed that waste represents a relatively large percentage of production costs (Koushki and Kartam, 2004). Distinct types of wastes have been measured in those studies, indicating that waste in construction has been understood in several different ways. Consequently, a wide range of measures, such as excess consumption of materials, has been taken (Bossink and Brouwers, 1996). Koskela (1992) defined waste as "any inefficiency that results in the use of equipment, materials, labor or capital in larger quantities than those considered as necessary in the production of a building". Early in the 1990s, Stokoe *et al*. (1999) reported that construction and demolition waste took up about 65% of Hong Kong's landfill space. In the United kingdom, Deaner (1991) claimed that an office building that can be built with 35,000 tons of steel today required 100,000 tons 30 years ago. Also, According to Ferguson *et al*. (1995) over 50% of the waste in a typical United Kingdom landfill could be construction waste. In Australia, Craven *et al*. (1994) reported that construction activity generates 20 to 30% of all waste deposited in Australian landfills. In Chile, Serpell and Labra (2003) reported that of the 3.5 million tons of Construction and Demolition waste generated in 2003, only 10% is placed in authorized and controlled landfill sites. In the United State, construction and demolition waste represents about one-third of the volume of materials in landfills. In the European Union, it is estimated that 0.5 to 1 ton per capital of construction and demolition waste is generated annually (Neo and Koh, 1995).

RESEARCH METHOD

Questionnaire design: The questionnaire is designed to serve the study's objectives: to highlight the construction material waste, identification, relevance and causes.

Contents of the questionnaire: The questionnaire is divided into the following four sections:

- **Instructions and participants' demography:** This section defines the key terms in the study and provides participants with instructions on completing the questionnaire. It also elicits general information about the respondents such as the contact address, their expertise in the field of construction industry and the size of the company they work at.
- **Construction material waste importance:** This section is concerned with ranking a list of construction material waste suggested by the researchers. The respondents were required to rank the list of building material waste based on their importance using a 5-point scale as follows: very high, high, moderate, low and very low (on 5 to 1 point scale).
- **Causes of building material waste:** This section addresses the possible causes for construction material waste. 40 causes were identified through the literature review and the input of local experts in construction projects. The respondents were required to rank the list of waste causes based on their importance using a 5-point scale as follows: very high, high, moderate, low and very low (on 5 to 1 point scale).

Pilot study: A pilot study was conducted to verify the questionnaire and to ensure that the information received from the contractors was be appropriate to the objectives of this study. This was done by sending a draft of the questionnaire with a cover letter to three experts in the construction business asking them to evaluate the content validity of the questionnaire. After receiving the answers from the selected experts, the questionnaire was slightly modified based on the received feedback.

Data analysis: The importance of the waste rate of the listed construction material and the suggested waste causes are ranked by the measurement of the importance index. The following formula is used to rank them based on the level of importance as identified by the participants.

$$\text{Importance Index (IMP.I) } (\%) = \sum a\,(n/N) \times 100/5 \quad (1)$$

where,

a = The constant expressing weighting given to each response (ranges from 1 for very low up to 5 for very high)
n = The frequency of the responses
N = Total number of responses

Statistical analysis: A number of statistical techniques are used to interpret the dispersion, compactness and the degree of homogeneity of the responses for the importance of waste rates and the influence of the identified waste causes as assessed by the contractors. These techniques include computation of the weighted mean, standard deviation (Sn) and Coefficient of Variation (C.V).

RESULTS AND DISCUSSION

Participants: The questionnaire was sent out to a total of 50 contractors in the Northern region of KSA requesting them to rank the identified waste causes and waste rates in terms of importance using an ordinal scale. A total of 42 contractors filled out and returned the questionnaire. The response rate is 84% which is a good rate. This result was achieved by continuous and close contact with contractors. The participating contractors have an average of more than 10 years of experience in building construction projects.

Ranking of waste rates: Table 1 shows the importance index value and the ranking of the considered building materials. Six materials are considered in this study: steel reinforcement, concrete, cement, sand and stones, bricks and timber broad. The contractors ranked "steel reinforcement" in the first position with an importance index value of 74.50, followed by timber broad, concrete, cement, bricks and sand and stones, respectively (with importance index value of: 74.00, 71.00, 67.00, 65.50 and 62.00, respectively). Results indicate that waste rates in all considered building materials are of high importance (IMP.I >60).

Ranking of waste causes in building construction: In this study, 40 material waste causes in building projects were identified and ranked by measurement of importance index according to Eq. (1). Table 2 shows the importance index value and the ranking of the identified causes. Results show the following:

- There are 2 causes with importance index higher than 80.
- There are 14 causes with importance index between 60 and 80.
- The minimum importance index is 37.30. These results indicate that the identified causes are highly relevant to the problem of material waste in building construction projects.

Table 1: Ranking of building material waste rates

Building material	IMP.I	Rank
Steel reinforcement	74.50	1
Timber broad	74.00	2
Concrete	71.00	3
Cement	67.00	4
Bricks	65.50	5
Sand and stones	62.00	6

Table 2: Causes importance index value and the ranking

Waste cause	IMP.I	Rank
Over ordering or under ordering due to mistakes in quantity surveys	81.5	1
Selection of low quality products	80.34	2
Materials supplied in loose form	79.15	3
Wrong orders	78.78	4
Poor resource management	76.63	5
Lack of coordination among crews	74.12	6
Design and construction detail errors	73.2	7
Using untrained labour	71.11	8
Insufficient instructions about handling	68.82	9
Incorrect material handling	66.57	10
Bad relation between the labourers and the management	64.13	11
Improper planning for required quantities	63.13	12
Lack of on- site material control	62.8	13
Design changes	61.65	14
Damage materials on site	61.32	15
Rework due to workers' mistakes	60.75	16
Selecting the lowest bidder contractor/ subcontractor	59.18	17
Poor communication and coordination between project participants	57.7	18
Use of wrong material, thus requiring replacement	55.17	19
Insufficient instructions about storage and stacking	54.8	20
Rework that does not comply with drawings and specifications	53.22	21
Wrong storage of materials	52	22
Lack of on- site waste management	51.6	23
Theft and vandalism	50.46	24
Inadequate or incorrect specification	49.2	25
Inadequate stacking and insufficient storage on site	48.8	26
Errors in contract documents	47.4	27
Shipping and suppliers' errors	47.16	28
Damage during transportation	46.84	29
Poor schedule to procure the materials	45.06	30
Equipment malfunctioning	44.1	31
Changes in material prices	43.4	32
Lack of attention paid to dimensions of products	43.2	33
Complicated design	42.85	34
Slow drawing revision	42.05	35
Improper methods of unloading	41.66	36
Contract documents incomplete at commencement of construction	40.17	37
Manufacturing defects	40.11	38
Lack of supervision	39	39
Difficulties for delivery vehicles	37.3	40

The input of contractors indicates that "over ordering or under ordering due to mistakes in quantity surveys" is the top indirect cause affecting material waste with an importance value of 81.50. "Selection of low quality products" was ranked 2nd with an importance index value of 80.34. "Design and construction detail errors" was ranked 3rd with an importance index value of 79.15. This result is justified, as design mistakes may cause rework that leads to material waste. "Materials supplied in loose form" was ranked 4th with an importance index value of 78.78. "Poor resource management" was ranked 5th with an importance index value of 76.63. This result is justified, as poor resource management may lead to many problems on site such as: rework, change orders, claim which lead to material waste.

On the other hand, results indicate that the bottom causes of material waste are: difficulties for delivery vehicles, lack of supervision, manufacturing defects, the incompletion of contract documents at the commencement of construction and improper methods of unloading with importance index value of 37.30, 39.00, 40.11, 40.17 and 41.66, respectively.

Table 3: Statistical analyses of contractors' responses for material waste rates in building projects

Building material	X'	Sn	C.V (%)
Steel reinforcement	3.73	0.51	13.80
Timber broad	3.70	0.48	13.08
Concrete	3.55	0.52	14.65
Cement	3.35	0.57	17.13
Bricks	3.28	0.60	18.44
Sand and stones	3.10	0.58	18.71

Statistical analysis: Table 3 and 4 present the statistical analyses for the responses on the importance of materials waste rates and material waste causes as assessed by contractors. The tables contain the computation of the weighted mean, standard deviation and coefficient of variation. They are used to interpret the dispersion, compactness and the degree of homogeneity of the collected data.

Table 3 shows that the standard deviation and coefficient of variation of waste rates have reasonable values (i.e., the maximum standard deviation is 0.88 and the maximum coefficient of variation is 47.26%). Table 4 also shows reasonable values for standard deviation and coefficient of variation of waste causes

Table 4: Statistical analyses of contractors' responses for material waste causes in building projects

Waste cause	X'	Sn	C.V (%)
Over ordering or under ordering due to mistake in quantity surveys	4.08	0.37	9.01
Selection of low quality products	4.02	0.42	10.53
Materials supplied in loose form	3.96	0.53	13.51
Wrong orders	3.94	0.5	12.73
Poor resource management	3.83	0.53	13.96
Lack of coordination among crews	3.71	0.6	16.24
Design and construction detail errors	3.66	0.64	17.36
Using untrained labours	3.56	0.6	16.93
Insufficient instructions about handling	3.44	0.59	17.17
Incorrect material handling	3.33	0.69	20.77
Bad relation between labors and management team	3.21	0.69	21.56
Improper planning for required quantities	3.16	0.7	22.26
Lack of on- site material control	3.14	0.65	20.59
Design changes	3.08	0.6	19.52
Damage materials on site	3.07	0.65	21.09
Rework due to workers' mistakes	3.04	0.58	19.08
Selecting the lowest bidder contractor/ subcontractor	2.96	0.56	18.83
Poor communication and coordination between project participants	2.89	0.78	27.06
Use of incorrect material, thus requiring replacement	2.76	0.83	29.92
Insufficient instructions about storage and stacking	2.74	0.84	30.53
Rework that don't comply with drawings and specifications	2.66	0.74	27.66
Wrong storage of materials	2.6	0.76	29.17
Lack of on- site waste management	2.58	0.77	29.83
Theft and vandalism	2.52	0.71	28.29
Inadequate or incorrect specification	2.46	0.67	27.19
Inadequate stacking and insufficient storage on site	2.44	0.79	32.45
Errors in contract documents	2.37	0.76	32
Shipping and suppliers' errors	2.36	0.66	27.89
Damage during transportation	2.34	0.68	29.04
Poorly schedule to procurement the materials	2.25	0.76	33.66
Equipment malfunctioning	2.21	0.76	34.39
Changes in materials prices	2.17	0.8	37.01
Lack of attention paid to dimensions of products	2.16	0.84	38.73
Complicated design	2.14	0.88	41.14
Slow drawing revision	2.1	0.75	35.54
Improper methods of unloading	2.08	0.8	38.55
Contract documents incomplete at commencement of construction	2.01	0.8	39.98
Manufacturing defects	2.01	0.85	42.27
Lack of supervision	1.95	0.81	41.76
Difficulties for delivery vehicles	1.87	0.87	46.66

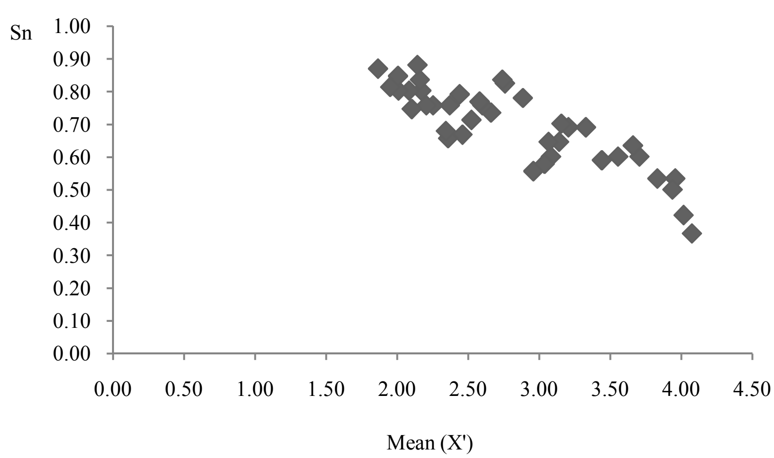

Fig. 1: Mean versus standard deviation

(i.e., the maximum standard deviation is 0.60 and the maximum coefficient of variation is 18.71%).

Illustrations in Fig. 1 and 2 show the following:

- Visually, Fig. 1 indicates good data consistency and high agreement between contractors on the importance of the identified waste causes.

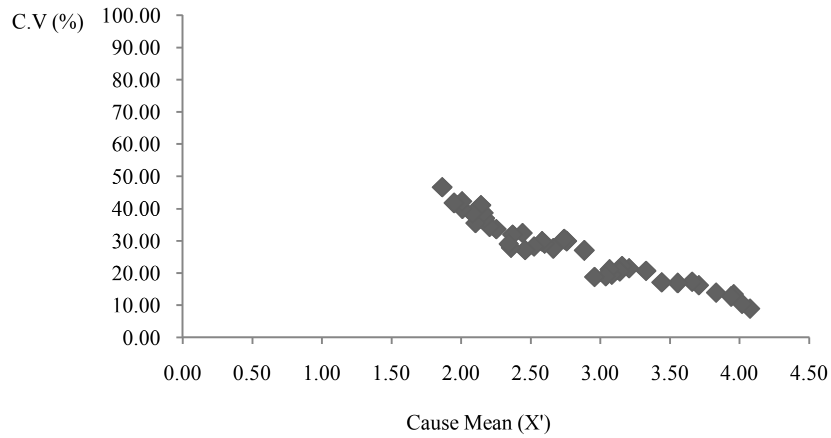

Fig. 2: Cause mean versus coefficient of variation

- Figure 2 shows that the values of variation coefficients of waste causes are reasonable.
- Figure 2 indicates that the coefficient of variation decreases as the weighted cause mean increases, meaning that the participants are highly agreed on the impact of the top waste causes.

CONCLUSION

The construction industry is one of the main sectors that provide important ingredients for the development of national economy. However, it could also include a huge number of non value added activities such as construction material waste which impact environmental regulations and cause huge financial losses and safety concerns. This study aims at identifying causes of material waste in building construction projects from the contractors' viewpoint. To do so, 42 contractors completed a structured questionnaire survey. 40 waste causes were identified through data collected form local construction experts. The contractors were asked to rank the identified waste causes according to their level of importance. The analysis of the identified causes indicated that the top five important causes are: over ordering or under ordering due to mistakes in quantity surveys, selection of low quality products, design and construction detail errors, supplying materials in loose form and poor resource management. On the other hand, results indicate that the bottom causes of material waste are: difficulties for delivery vehicles, lack of supervision, manufacturing defects, incompletion of contract documents at the commencement of construction and improper methods of unloading with importance, respectively.

The study also investigates material waste rates. 6 building materials were considered in the questionnaire survey. The contractors were asked to rank the considered materials according to their level of importance. The contractors' input ranked "steel reinforcement" in the first position, followed by timber broad, concrete, cement, bricks and sand and stones, respectively.

The statistical analysis of the gathered data shows the following:

- There are 2 causes with importance index higher than 80.
- There are 14 causes with importance index between 60 and 80.
- The minimum importance index is 37.30.
- The results of standard deviation and coefficient of variation show reasonable values and good data compactness and consistency.
- The results of standard deviation and coefficient of variation show high agreement between contractors on the impact of the top waste causes.

These results indicate that the identified causes are highly relevant to material waste over the building projects in Saudi Arabia Finally, the study highly recommend implementing lean manufacturing principles and utilizing Kanban inventory control to eliminate waste of quantity ordering mistakes.

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