Fresh ready-mixed concrete waste in construction projects: a planning approach

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**Abstract**

In the current study, how planning and truck-mixer based waste amounts per 1 m\textsuperscript{3} fresh ready-mixed concrete (RMC) can be determined was presented. Toward this aim, the formation process of the fresh RMC waste in construction projects was first introduced in a detailed manner, together with an in-depth literature review in this specific domain of the construction engineering and management. Then, the measurement procedure of the waste amount or coefficient of the fresh RMC was revealed and discussed as a practical and creative planning knowledge. Hence, a useful and realistic waste management perspective about the cost and potential environmental savings of the RMC waste was drawn.

Keywords: Concrete waste; construction projects; fresh concrete; project planning; ready-mixed concrete

**1. Introduction**

Today, construction industry tries to deal with enormous amounts of wastes as they are very damaging to the environment. However, it is very hard to assert that the construction industry has generally constituted and improved its waste-based business culture so far. In order to reveal the current position of the construction industry as a whole in terms of types and amounts of construction wastes, it is inevitable that various types of estimates and plans on sub-sectors of the construction industry should be carried out.

In this context, how planning and truck-mixer based waste amounts per 1 m\textsuperscript{3} fresh ready-mixed concrete (RMC) can be determined was presented in the current paper as a part of an on-going research project. This is because, in a reinforced-concrete building project, concrete can have a big share of about 10\% of the total project budget [1]. Of course, these amounts can be single numbers or interval-based values. Thus, while preparing their proposals, construction contractors can better estimate both amount and cost of RMC by means of these numerical values, and can take some preventive measures to decrease these wastes. Project owners can make realistic estimates on the total project cost by employing these unit waste amounts in the calculation of the planned budget. With an accurate estimation of the amount of the RMC waste, RMC firms can save both RMC and its raw materials (i.e., aggregate, cement, and water) by related preventive and recycling efforts. In addition, by revealing the causes of the formation of the fresh RMC waste, responsibilities of contractors and RMC producers can be determined to prevent and minimize this kind of wastes. From another perspective, according to TRMCA [2], RMC of 102 million cubic meters

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was produced in Turkey in 2013. Considering this huge consumption volume of RMC, it is evident that, both in Turkey and in other countries that consume high amounts of RMC, the determination of accurate amount of the RMC waste has a vital aspect for customers, producers, and society in terms of cost-effective business, sustainable natural resources, energy-saving processes, and environmental pollution. Moreover, this amount can be used in the solution of conflicts about the amount of RMC delivered or about the loss of RMC between RMC producers and consumers.

2. Fresh RMC waste

In construction projects, amounts of materials used both in the cost estimating process by owners or their consultants and in the cost planning process by main contractors are determined through detailed quantity surveying studies on project drawings. However, given the current on-site practices, it is nearly inevitable that there are almost always some natural differences between planned values calculated in quantity surveying studies and real material amounts used in construction job-sites because of some reasons such as poor workmanship and losses during transportation and placing. In order to take into account these differences, planning engineers and technical personnel in construction projects assign some practical specific coefficients or percentages without making any measurement, but by being based totally on their own experience. Basically, they multiply these specific values by amounts of related materials and finally find out the last quantities that will be used in construction projects [3,4,5]. However, these last material quantities become different from those in practice owing to the fact that these coefficients cannot be successfully estimated and that some unexpected wastes are thus automatically created. In fact, this is because material wastes cannot be completely avoided and prevented due to different production methods and products in sites and unqualified quantity surveyors and estimators [6].

Concrete waste is among the most important types of material wastes in construction projects. They accounts of approximately 50-55% of the total construction waste generation by weight [7,8,9]. Numerous academic researchers in theory and many concrete manufacturers in practice attach significant importance to recycling and reusing issues of the concrete waste. This kind of studies in the related literature have usually been directed to the use of the crushed concrete waste either as a road-base fill material or in place of the virgin aggregate for the new concrete and asphalt pavement [10,11,12]. However, in order to sustain these recycling and reusing efforts in terms of commercial and environmental purposes, the potential amount of the crushed concrete waste (i.e., artificial aggregate) that can be produced in a plant and in a region should be clearly known. In this regard, only a few scientific research studies on the determination of the concrete-focused version of the above-mentioned coefficients or percentages exist in the literature to minimize such wastes at inception. Details of these researches are given in Table 1 below.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Country</th>
<th>Number of construction materials observed</th>
<th>Type and number of projects observed</th>
<th>Observation period</th>
<th>Average amount of concrete waste by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soibelman [13]</td>
<td>Brazil</td>
<td>7</td>
<td>4 housing and 1 commercial building projects</td>
<td>4-5 months</td>
<td>13.2%</td>
</tr>
<tr>
<td>Isatto et al. [14]</td>
<td>Brazil</td>
<td>16</td>
<td>35 construction projects</td>
<td>4-6 months</td>
<td>9.5%</td>
</tr>
<tr>
<td>Bossink and Brouwers [15]</td>
<td>Holland</td>
<td>9</td>
<td>5 housing projects</td>
<td>14 months</td>
<td>3%</td>
</tr>
<tr>
<td>Poon et al. [16]</td>
<td>Hong Kong</td>
<td>10</td>
<td>20 public housing projects and 2 office blocks</td>
<td>Not available</td>
<td>3-5%</td>
</tr>
<tr>
<td>Poon et al. [17]</td>
<td>Hong Kong</td>
<td>11</td>
<td>5 housing projects</td>
<td>20 months</td>
<td>2.5%</td>
</tr>
<tr>
<td>Tam et al. [18]</td>
<td>Hong Kong</td>
<td>5</td>
<td>18 construction projects</td>
<td>Not available</td>
<td>4-6.8%</td>
</tr>
<tr>
<td>Baytan [19]</td>
<td>Turkey</td>
<td>4</td>
<td>8 construction projects</td>
<td>1-5 months</td>
<td>6.1%</td>
</tr>
<tr>
<td>Li et al. [20]</td>
<td>China</td>
<td>6</td>
<td>1 building project</td>
<td>1 month</td>
<td>1%</td>
</tr>
</tbody>
</table>
As can be seen from the above-mentioned all percentage values based on researches, the amount of the concrete waste varies in a wide interval changing between 1% and 13.2%. From the methodological perspective, no research presented in Table 1 has carried out a direct quantitative measurement in places the concrete waste can be born. Numerical values in these studies have been compiled by subtracting the amount of concrete in the bill of quantities from that in project drawings. In other words, these values have been calculated using the following Equation 1 where \( V_{\text{percentage}} \) is the percentage of the concrete waste, \( V_{\text{purchased}} \) is the amount (i.e., volume) of concrete purchased, and \( V_{\text{design}} \) is the amount of concrete measured from project drawings,

\[
V_{\text{percentage}} = \left( V_{\text{purchased}} - V_{\text{design}} \right) / V_{\text{design}}
\] (1)

However, in case of a difference between \( V_{\text{purchased}} \) and \( V_{\text{design}} \), it cannot be asserted that the concrete waste is formed. Even a practical difference of 1 cm between the real position of formwork and its must-be position can lead to a significant deviation especially when the amount of concrete to be poured is very high. In addition, as can be seen from all these previous studies, there is no research investigating the amount of the concrete waste only. This is because in these researches site- or project-focused calculations rather than RMC plant-focused measurements as in the present study have been made due to the high number of different construction materials followed. Therefore, a direct quantitative measurement has been performed neither in RMC plants, where concrete is produced, nor during the discharge of the leftover concrete. In practice, this excessive concrete can be poured in site, in RMC plant, or during transportation. In this context, the amount of concrete is not controlled in these three stages, and the concrete waste poured in RMC plants or during transportation is overlooked. Thus, measurements calculated become prone to serious errors. Moreover, by this methodology, reasons behind the formation of the concrete waste cannot be determined clearly. Therefore, some of the above-mentioned studies [15,17] try to reveal these reasons and their importance levels by means of questionnaire surveys applied to site/project managers instead of employing a direct measurement technique.

Within various categories of the concrete waste, over-order of concrete is the major contributor among others, according to Tam and Tam [9]. A £400 million of RMC is dumped in the UK each year because construction sites inaccurately order quantities [21]. Similarly, about 8-10 tons of the fresh concrete waste can be produced every day from a batching plant with a daily output of 1000 m$^3$ of concrete [11]. From a global perspective, it is estimated that over 125 million tons of the returned concrete or 0.5% of the total concrete production are generated as waste every year, confirming that it is a relevant part of the construction waste and represents a heavy burden for RMC plants [22]. Reasons behind the formation of the fresh concrete waste can be listed as follows,

- wide-margin orders of contractors’ planning engineers for RMC – the amount allowed by quantity surveyors is generally about 10% more than that in project drawings [23,9] because (i) the additional concrete may not be immediately produced especially in busy periods of a batching plant and thus some undesired joints may be formed if the ordered concrete is insufficient and cannot be delivered in time and (ii) estimators find it easier to over specify rather than calculate quantities accurately [24]
- the incorrect calculation of quantity, which is usually based on orders given by workers instead of civil engineers [1]
- the poor workmanship during the concrete-pouring activity
- the residual or adhesive concrete in truck-mixers [15,25,17].

3. Measurement of the fresh RMC waste

The volume of RMC filled into a truck-mixer (\( V_{\text{total}} \)) by a computerized automatic system in an RMC plant is first calculated by dividing the weight of the total fresh RMC (\( W_{\text{total}} \)) into the weight of the unit volume of the fresh RMC (\( \Delta_{\text{concrete}} \)) as in Equation 2,

\[
V_{\text{total}} = W_{\text{total}} / \Delta_{\text{concrete}}
\] (2)
Second, the residual RMC in the truck-mixer, which cannot be poured and thereby returns to the plant after delivery, is taken in the plant by adding some water into the truck-mixer and weighed. The original weight of it ($W_{waste}$) and those of its ingredients (i.e., aggregate, cement, and water) are determined by material experiments in laboratories of the related project-partner university and batching plant. It is of course hard to test whole RMC wastes in truck-mixers because of their huge total amounts. Therefore, before the measurement process in the research, samples were taken from each truck-mixer for each class of concrete and were analyzed in detail. As a result, average coefficients were determined to directly calculate original weights of ingredients through the total weight of the fresh residual RMC of which additional water was filtered. This application is periodically performed once three months to observe if these coefficients vary. The sum of original weights of ingredients gives the original weight of the residual RMC in the truck-mixer ($W_{waste}$). The volume of this sum ($V_{waste}$) is calculated by Equation 3,

$$V_{waste} = W_{waste} / \Delta_{\text{concrete}}$$  \hspace{1cm} (3)

Thus, the volume of RMC poured in the site or delivered to the client ($V_{poured}$) can be clearly expressed as in Equation 4,

$$V_{poured} = V_{total} - V_{waste}$$  \hspace{1cm} (4)

In this context, the possible relationship between $V_{waste}$ and the volume of drum of the truck-mixer is also investigated statistically by following truck-mixers of 9, 11, and 12 m³, which are commonly used in the industry. Another possible relationships investigated are between $V_{waste}$ and the class of concrete and between $V_{waste}$ and ingredients' (i.e., sand, gravel, cement, and water) proportions.

As most RMC orders in the construction market are higher than 10 m³, it can be accepted that RMC is usually delivered by more than one truck-mixer. Through Equation (5), the percentage or the unit volume of the residual/adhesive RMC waste in the truck-mixer ($V_{mixer}$) is found out. This is the plant-based cause of the waste generation problem. In theory, the drum should be watered after each order and before idle times. However, in practice, it is performed once per truck-mixer only at the end of the working day because of busy working conditions of truck-mixers.

$$V_{mixer} = \left( \frac{\sum_{i=1}^{n} V_{waste-i}}{\sum_{i=1}^{n} V_{total-i}} \right) \times 100$$  \hspace{1cm} (5)

Client- or contractor-based waste generation factors mentioned above as wide-margin orders, the incorrect calculation of quantity, and the poor workmanship, are also examined in terms of their shares in the unit volume of the RMC waste. As can be given in Equation (6), the potential volume of the RMC waste ($V_{client}$) depends both on the volume of RMC ordered by client ($V_{ordered}$) and on the total volume of RMC poured by multiple truck-mixers in site. However, $V_{client}$ is an imaginary waste unless a truck-mixer returns to the batching plant from site together with the unwanted or unused fresh RMC more than the probable residual/adhesive RMC. This becomes clear when a truck-mixer that has already come back to the plant is weighed. This is because RMC plants produce and deliver RMC step by step as much as the drum of a truck-mixer can include. The production and loading procedure of the whole RMC in a drum takes five minutes only. It means that orders are met in a retail system rather than a wholesale system where all the items of a product are manufactured and wait for delivery. From another perspective, even if a truck-mixer returns with a considerable amount of RMC, it is sent to another project that demands for a same or smaller class of concrete although it is difficult to match highly specific mix types with suitable customers at short notice. However, if there is no such a project, the returned concrete is called as the fresh waste and a limited number of the dosing centrals have resources to handle this waste in their yard indeed. Such wastes are also recorded in this research.
Thus, the unit waste volume or percentage that can be used by client ($V_{estimating}$) in estimating the real volume of RMC to be placed is determined through Equation (7),

$$V_{estimating} = \left( V_{client} / V_{ordered} \right) \times 100$$

Here, as the first option, $V_{client}$ can be a negative value. This denotes that the concrete quantity has been calculated incorrectly by client and/or that $V_{mixture}$ has been ignored by client and RMC plant. In contrast, $V_{client}$ can be a positive value. In this case, either $V_{estimating}$ is allocated by client for order or there can be client-based three causes such as wide-margin orders, the incorrect calculation of quantity, and the poor workmanship. In the present research, these are investigated by means of the direct observation and communication in sites and measurement in RMC plants. While calculating $V_{estimating}$, possible relationships between this value and the type of project and between it and the type of formwork are also examined statistically together with the causes behind these relationships.

4. Conclusions

In this study, a detailed step-by-step procedure to measure planning and truck-mixer based waste amounts per 1 m$^3$ fresh RMC was presented. This was performed in the light of the formation process of the fresh RMC waste in construction projects.

As practical/industrial and social implications, waste coefficients that can be obtained by following the procedure explained throughout the present paper can be used by construction contractors and project owners in estimating and accounting and by RMC firms in saving natural resources and energy and in preventing the environmental pollution and potential conflicts between parties. As a research implication, the following values can be computed through unit waste amounts in a future study,

- **Annual fresh RMC waste production amounts of RMC plants in a country**: The total RMC production amount in a country in a year can be multiplied by $V_{mixture}$. Also, the share of the each class of concrete in this waste amount can be multiplied by the corresponding unit RMC cost. Thus, the estimated cost of the total RMC waste can be determined.

- **Approximate amounts of ingredients (i.e., aggregate, water, and cement) that can be saved by RMC plants in a country in a year**: As proportions of ingredients used for different classes of concrete are recorded in this research, these proportions can be multiplied by the computed waste amount of the each class of concrete. Also, these approximate amounts can be multiplied by the corresponding unit costs of these ingredients. Thus, the total cost of savings can be revealed.

Acknowledgements

The authors gratefully acknowledge the managers and employees of the batching plants for their generous collaboration and contributions. The authors also thank financial supports provided by Committees on Research Grants of Akdeniz University and Bulent Ecevit University. This study is based on a research project which is financially supported by the Scientific and Technological Research Council of Turkey (TUBITAK) under the grant number MAG-113M428.

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