Dynamic Modeling of Cement In-use Stocks in United States

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The key attributes of sustainable infrastructure systems are – extended service life, enhanced performance, optimal life cycle costs, and minimal environmental life cycle impacts including the use of virgin raw materials. The rate of addition of new stock and the repair of existing stock are key determinants of infrastructure sustainability. The condition and performance of, especially, concrete infrastructure, in the United States has shown an alarming decline and it is anticipated that billions of dollars of investment will be required over the next decade to replace and/or rehabilitate existing structures. Globally, contemporary concrete production is approximately 12 – 15 billion metric tons [1]. Cement is an essential component of concrete, usually in the range of 10-15% by volume. The production and use of cement are both energy- and material-resource intensive. The objective of this study is to characterize the stocks and flows of cement mobilized and utilized during the twentieth century in United States using the generic cement life cycle (Figure 1). The motivation for estimating historical inventories of cement stocks and flows is to provide accurate informed estimates of contemporary cement in-use stocks in U.S.

![Figure 1. Generic life cycle of cement](image-url)
infrastructure and future discards to relevant stakeholders such as federal highway administration, department of transportation, public/private utilities, and the construction and cement industries.

A dynamic substance flow model was developed using time-series data on apparent cement consumption and lifetime distributions for each cement end-use infrastructure application. There is buildup of stock when the inflows exceed the outflows of the use reservoir. The lifetime distribution determines the residence time of the in-use stock in the use reservoir. The consumption of cement has increased six-fold over the last fifty years (Figure 2). During the last century, the consumption of cement in the United States was approximately 4.5 billion metric tons. Apparent cement consumption was partitioned into various end-use markets such as roads, bridges, highways, buildings (residential, commercial), water and wastewater utilities, based on historical and contemporary data available from the Portland Cement Association and United States Geological Survey. For the time periods where cement end-use market share data were not available, missing values were interpolated based on existing trends. The contemporary cement end-use market in United States for the year 2000 is shown in Figure 3. The use of cement for road infrastructure accounts for about one-third of this market.

Dynamic lifetime models based on statistical Weibull distribution were constructed for each of the end-uses. The Weibull distribution is the most commonly used and preferred distribution in lifetime modeling of products [4]. The model-derived estimate of the in-use cement stocks in United States is in the range of 2.5-3 billion metric tons. This indicates that 55-70% of cement utilized during the last century is still in use. A sensitivity analysis of the results shows that uncertainties in choosing the appropriate Weibull lifetime distribution exert a stronger influence on the results than do variations in cement end-use market values.

Figure 2. Apparent consumption of cement in U.S. [2].

Figure 3. Cement end-use market in U.S. in the year 2000 [3].
References