SOURCES OF UNCERTAINTY IN CONCRETE MATERIAL SUSTAINABILITY ANALYSIS

Hokkaido University	Ph.D. Student	JSCE Student Member	Joel Opon
Hokkaido University	Associate Professor	JSCE Member	Michael Henry

1. Introduction

The indicator-based approach to evaluating concrete sustainability has been criticized due to its structural instability that relies on both objective and subjective inputs. It is suspected that uncertainties from these inputs could propagate unaccounted into the analysis, thus undermining the result. To dissuade the negative perceptions on concrete sustainability, it is crucial to understand the causes of these uncertainties. Some forms of uncertainty are due to a sophisticated analysis framework. In an indicator-based assessment, for instance, the manner of indicator selection imparts different magnitudes of uncertainty. Conceptually, therefore, the uncertainty inherent to concrete sustainability could be minimized by modifying the analysis framework. In the following sections, various methodological sources of uncertainty are introduced and discussed. A hypothetical calculation is also presented, showing the effect of uncertainty on decision-making. The treatment of uncertainty is of paramount importance because stakeholders depend on the outcome of the analysis to make robust decisions.

2. Sources of Uncertainties

2.1. Linguistic uncertainty

Linguistic uncertainty in concrete sustainability emerged because of the concept's vagueness, which is evident in the lack of consensus on what constitutes sustainable concrete. This can be attributed to concrete's dynamic nature and diverse applications. Precise definition, however, is required to build a robust analysis framework and eliminate confusion in indicator selection.

2.2. Lack of central framework

While researchers race to propose a multitude of methodologies on concrete sustainability, sustainability is not finding its way easily into regulations, codes, or standards [1]. As a consequence, methodological conflicts arise, producing contrary conclusions on the sustainability of concrete. Furthermore, different frameworks entail different magnitudes of uncertainty. For instance, a simplistic and straightforward process may have higher magnitudes of uncertainty compared to an iterative framework, which allows input to be constantly updated depending on the level of acceptable uncertainty.

2.3. Indicator Selection

The common practice of indicator selection depends on expert opinion, or on participatory selection by stakeholders. Critics of both selection methods argue that they are subjective, in that the included indicators may not properly measure the system they represent. In a participatory approach, for instance, it is difficult to strike a balance between material performance and environmental indicators. The usual criteria for indicator inclusion are relevance and measurability.

The uncertainties due to indicator selection arise from the exclusion or inclusion of indicators into the set; for instance, the exclusion of some environmental indicators due to data unavailability. This uncertainty is unavoidable because of the information gap. Quantifiable uncertainty, on the other hand, emanates from the exclusion of measurable indicators with less relative variability, or intentional omission because they are perceived as less important.

2.4. Data

The uncertainty related to indicator data originates from three sources: data quality, choice of data, and missing data. Data quality uncertainty is due to experimental execution or the use of inappropriate inventory data; for instance, using average concrete compressive strength with a coefficient of variation beyond the limit. The uncertainty from the choice of data is due to the arbitrary selection of time-varying quantities. The choice between 28- or 56-day concrete strength, for example, may produce contrasting results. The other source of uncertainty is imputation of missing data from existing sources. For instance, the inadvertent use of global average values in lieu of country-specific data as inputs (e.g., CO_2 emissions from cement production).

2.5 Normalization

The purpose of normalization is to compare disparate indicators [2]. In concrete, normalization is a challenge because of the absence of a standard mix to which alternatives can be compared. For example, when normalizing compressive strength, researchers resort to

Keywords: sustainable concrete, sustainability analysis, uncertainty analysis, indicators
Address: Kita-13 Nishi-8, Kita-ku, Sapporo, Japan. TEL +81-011-706-6180

using a pre-selected concrete mix as a reference (usually normal concrete mix). The selection of this mix can be construed as subjective, which might not fit the purpose of evaluation (e.g., high strength concrete applications).

2.6 Weighting of indicators

The weighting of indicators is a concern in concrete sustainability because of the perceived subjectivity in assigning weighs. Weights are assigned to represent the relative importance of the indicators; for instance, prioritizing material performance over environmental indicators because current codes on concrete lack emphasis on environmental sustainability. A popular technique to weigh indicators is participatory judgment by stakeholders, which is highly subjective. Other techniques in the literature include equal weighting (EW) and analytic hierarchy process (AHP). The diversity of weighting techniques introduces a methodological uncertainty to the analysis because weights introduce trade-offs and may compensate poor performance of an indicator. However, in many cases, the declared importance of a single indicator and its main effect may differ [3].

2.7 Indicator aggregation

Some researchers protest the concept of aggregating indicators to a single value because it dilutes the original meaning of indicators, making it the primary source of uncertainty. However, because of its ability to reduce a complex concept, such as sustainable concrete, communicating it to decision makers is easy. The choice of aggregation method also raises objections from critics because of the compensatory nature of some techniques, which means the good performance of one indicator can offset the poor performance in another [2]. Two popular methods used to aggregate indicators are linear (LN) and geometric (GM) aggregation. The choice of aggregation method is a form of methodological uncertainty and viewed to be subjective because of its weak underlying concept, which could overturn decisions.

3. Hypothetical Demonstration

Hypothetical concrete mixes (Table 1) were used to demonstrate the effect of weighting schemes (equal weighting – EW, and new weights – NW) and choice of aggregation method (LN and GM). The control acts as the reference, while A1 and A2 are the potential alternatives. Three normalized indicator values were used to represent sustainability: cost (economic), CO_2 (environment), and strength (social). An indicator value above the control is desirable. The values are chosen so that A1 is consistently above the control, while A2 performed better only in strength. A decision maker may face the dilemma on whether to choose A1, which balances all aspects or to consider the strength of A2 that is desirable for structures.

Figure 1 summarizes the results of the aggregation. LN-EW, LN-NW, and GM-EW consistently support A2 over A1, however, GM-NW completely reversed the trend. It is apparent that the choice of weighting and aggregation method both influence the result of the sustainability analysis, implying that the inception of uncertainties stems from methodological choices.

Table 1 Indicator normalized value and weighting

Series	Cost	CO2	Strength
Control	1.000	1.000	1.000
A1	1.007	1.020	1.092
A2	0.986	0.925	1.244
Weighting Schemes			
EW	0.333	0.333	0.333
NW	0.300	0.400	0.300

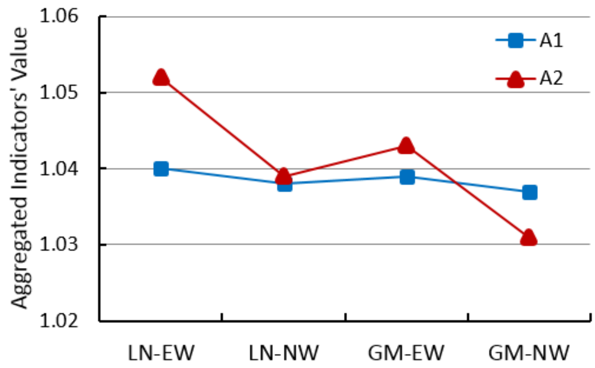

Figure 1 Result of indicator aggregation

4. Conclusions

The structural stability of a theoretical framework to evaluate the sustainability of concrete is dependent on methodological choices and treatment of uncertainties. Some uncertainties result from subjective choices that include indicator selection, weights assignment, and aggregation. The other unavoidable sources are due to information gap. Regardless of the source, the analysis should treat them transparently and objectively to arrive at a robust decision on concrete sustainability.

References

[1] Awad, K.W., "ACI's twofold approach to sustainability," American Concrete Institute – News Detail, 2018, Accessed: March 30, 2018.

[2] Burgass, M.J., Halpern, B.S., Nicholson, E., Milner-Gulland, E.J., "Navigating uncertainty in environmental composite indicators," Ecological Indicators, vol. 75, 2017, pp. 268-278.

[3] Paruolo, P., Michaela, S., and Saltelli, A., "Ratings and rankings: voodoo or science?" J. Royal Statistical Society, vol. 176, Part 3, 2013, pp. 609-634.