Many Concerns, One Objective

For ages, structures were built with one thing in mind: they should not fall down. Centuries ago, the strength of a structural design was estimated with experience, judgment, and perhaps testing of important components. Once the concept of stress came about the design was checked by comparing the calculated stress to some allowable stress. More recently, still for many decades, the stiffness of a structure, which determines the deflections, has also been checked to prevent discomfort by those using the structure. In modern codes the strength concern is formalized in ultimate limit-states, while the stiffness concern is checked with serviceability limit-states. Additional, but usually secondary limit-states exist in some codes, including fatigue, explosion-related limit-states, etc.

Allowable stress design has been used since the 1940s or 50s, and is still employed in some steel design codes. Limit-state design has been used since the 1970s and 80s, pioneered by reinforced concrete codes because it can be hard to calculate the stress in reinforced concrete components. Structural engineers designing against earthquake ground motion know that the 1990s and 00s brought yet another design paradigm, called performance-based engineering. In that approach, potential damage due to ground shaking is considered. Even if a structure does not fall down in an earthquake the damage may be unacceptably costly, as was observed for instance in the 1994 Northridge earthquake near Los Angeles. Thus, monetary cost of repairs and downtime were added to the list concerns that should be considered by a structural engineer.

In addition to the concerns outlined above, humans are increasingly realizing that some of our activities are causing unacceptable pollution and causing the climate to warm. Construction and operation of buildings and civil infrastructure is one of the activities that cause substantial emission of greenhouse gases. The report from the UN commission chaired by former Prime Minister of Norway Gro Harlem Brundtland established "sustainable development" as an important goal for humanity (United Nations 1987). In that seminal work, environmental impacts were not the only concern; economic growth and social equality are the other legs of the "three-legged stool" that the Brundtland Commission constructed to foster sustainable development.

To address the concerns relevant for a structural engineer it is useful to identify the phases in the lifecycle of a building, bridge, or other infrastructure. The following list suggests the activities, or events, that are taking place within each phase:

0. **Preparations**
   a) Production of electricity
   b) Production of fossil fuels
   c) Extraction of materials
   d) Manufacturing of construction materials
1. **Construction, repair, retrofit**
   a) Construction of prefabricated components
   b) On-site construction
2. **Ground shaking**

   a) Damage

3. **Operation**
   a) Heating
   b) Cooling
   c) Deterioration
4. **Demolition, deconstruction**
   a) On-site demolition and deconstruction work
   b) Recycling of materials
   c) Processing at landfill

One activity that takes place in several lifecycle phases and many other aspects of life is transportation:

T. Transportation
   a) Materials
   b) Workers
   c) Water
   d) Fuel

With all those activities there are concerns. The lists below are suggested, with two comments attached. First, some concerns, such as greenhouse gas emissions, depend upon the prediction of another concern; namely, consumption of energy in the form of electricity or fossil fuels. Second, notice that the ultimate and serviceability limit-states from current design codes, and also potential damage due to earthquakes, are baked into several of the concerns.

C. Consumption
   a) Consumption of materials
   b) Consumption of labour hours
   c) Consumption of fossil fuels
   d) Consumption of electricity
   e) Consumption of water

The final concerns, ultimately translated into monetary values (see the next section) are:

I. Costs
   a) Invoices
   b) Loss of business

II. Emissions
   a) Greenhouse gases
   b) Air pollution
   c) Toxic substances
   d) Waste

III. Human well-being
   a) Injuries, deaths
   b) Loss of residence
   c) Discomfort due to deflections and vibrations
   d) Respiratory health problems
   e) Poor aesthetics
   f) Discomfort due to noise

One Objective

The concerns listed above are numerous and dissimilar. How do you compare the invoice for a material purchase with the "cost" of poor respiratory health caused by emissions during production of that material? Some researchers suggest that the consideration of this multitude of concerns is a multi-objective decision problem, requiring so-called multi-objective decision techniques. A different approach is adopted on this website; all concerns are translated into monetary value. That is of course straightforward for direct costs paid through invoices, but less intuitive for, say, environmental impacts. Two points may help with the appreciation of this approach. First, think of the "carbon tax" suggested by William Nordhaus. At present, emission of a tonne of carbon is said to cost roughly $50. That idea, for which Nordhaus received the 2018 Nobel Prize in economy, is one example of expressing intangible concerns in monetary terms to promote good decision-making. Drew Shindell's monetary quantification of deteriorating human health due to pollution is another example (Shindell 2015). Second, note that even in multi-objective and multi-attribute decision-making it is ultimately necessary to place weights or preferences on each concern. Here it is argued that the translation into monetary value is a transparent way of doing that. That means that all **B** and **C** concerns require models to translate, say, greenhouse gas emissions into monetary cost values. Therefore, an example of a chain of models required in the suggested framework is:

- Model that predicts the consumption of fossil fuels [**U**.c] during transportation of materials [**T**.a] to the construction site [**1**.b]
- Model that predicts the emission of greenhouse gases [**II**.a] during the consumption of fossil fuels
- Model that predicts the cost of emitting greenhouse gases, i.e., [**II**.a]-cost

Perhaps the simplest example of modelling needs in this framework is:

- Model that predicts the invoice, i.e., direct cost [**I**.a] of the consumption of labour hours [**U**.b] during on-site construction [**1**.b]

Using the numbering introduced above it is possible to establish a big matrix of activities and concerns, with some cells requiring models, others not:

#	T	C	I.a	I.b	II.a	II.b	II.c	II.d	III.a	III.b	III.c	III.d	III.e	III.f
0.a	a-d	a-e												
0.b														
…														