An Exploratory Framework for Life-Cycle Sustainability Assessment of Road Salt in Winter Maintenance Operations

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Outline

- Background
- Complexities and Caveats in the LCSA Study
- Concepts of LCSA
- Preliminary LCSA Framework of Road Salt
- Conclusions and Future Research
Background

☐ Sustainability in highway winter maintenance has become a growing concern over the past decade

☐ Traditionally, nominal cost and effectiveness are the major criteria when selecting highway winter maintenance products

☐ Increasing concern over negative impacts
The production, distribution, storage and application of road salt are all contributing to the environmental footprint of highway operation.
The principles of sustainability generally put emphasis on triple bottom lines: economy, environment, and society.
Objective

- Conduct an initial exploration of the LCSA framework for road salt in winter maintenance operations
  - Anatomize the LCSA framework of road salt through analysis on the triple bottom line
  - Characterize the current state of thinking on the structure of LCSA framework
  - Identify appropriate factors and existing challenges toward developing a LCSA framework
Complexities and Caveats

- “Ripple effects”/indirect implications in environmental footprint and cost
  - Define the boundaries and time scale of analysis domain
  - Select appropriate temporal and spatial resolution for LCSA study
Complexities and Caveats

- "Ripple effects"/indirect implications in environmental footprint and cost
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- The cost, performance, and impacts of road salt application can be site-specific
Complexities and Caveats

- Many of the processes underlying the cost, performance and impacts of road salt application are stochastic in nature.
  - Current approaches for assessment are typically deterministic.
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The fate and transport of road salt in the environment and how they deteriorate the natural environment or assets are limited understood, let alone the quantification of costs and risks
Concepts of LCSA

Life-cycle assessment (LCA)

Social life-cycle assessment (SLCA)

Life-cycle costing (LCC)
Life-Cycle Costing (LCC)

Concept

*The sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life* (Woodward, 1997)

Procedure

- Define the cost elements of interest
- Define the cost structure to be used
- Establish the cost estimating relationships
- Establish the method of LCC formulation

Harvey’s life-cycle costing procedure
Life-Cycle Assessment (LCA)

- Concept

The compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (Handbook on life-cycle assessment, Guinee, 2004)

- Procedure

Diagram showing the process flow of Goal and scope definition, Inventory analysis, Impact assessment, and Interpretation with Direct Application.
Social Life-Cycle Assessment (SLCA)

- An aggregation of all phases of social impact assessment in a product’s life-cycle dimension

**Stakeholders**

- Worker
  - Child labor
  - Fair salary
  - Forced labor

- Consumer
  - Health & safety
  - Customer privacy
  - Transparency

- Local community
  - Community engagement
    - Access to immaterial
  - Cultural heritage

- Society
  - Technology development
  - Corruption
  - Contribution to economy

- Value chain actors
  - Supplier relationships
  - Fair competition
  - Promoting social responsibility

Five simplified stakeholder categories in the production system according to the UNEP’s guideline for SLCA (Fan et al., 2015)
Preliminary LCSA Framework

- LCC framework
- LCA framework
- SLCA framework
- Relationships of LCC, LCA, and SLCA in the LCSA Analysis
LCC Framework

- **Initial Capital Cost**
  - Manufacturing and storage,
  - Equipment, Implementation,
  - Transportation, Training, and Labor

- **Life of Asset**
  - Physical life, Technological life,
  - Economic life, Social and legal life

- **Discount rate**

- **Disposal cost**
  - Demolishing, Transportation,
  - Landfill, Labor

- **Information and feedback**

- **Uncertainty and sensitivity**
  - Usage frequency, Operating time
  - Demanding rate, Distribution,
  - Discount rate
LCA Framework

Goal and scope
Highway infrastructures
Functional units for 25 years design life

Inventory analysis
(Environmental burden)
Input and Output

Impact assessment
Impact categories
classification
Characterization
Normalization
Valuation

Interpretations
Sensitivity and uncertainty analysis
Iterative process to revise scope/goals, LCI, and LCIA
SLCA Framework

**Social benefits**
- Lives saved as a reduction of traffic accident rate
- Response time to medical emergencies
- Increase of the traffic efficiency
- Response time to medical emergencies
- Energy savings from the fuel cost
- Reduced wage loss from the working absence
- Reduction of delays in shipment

**Negative social impacts**
- Potential heart disease of people
- Decreased number of fish in lakes or streams
- Corrosion of concrete infrastructures and steel rebar or fiber reinforcement
- Corrosion of vehicles
SLCA Framework

- Challenges
  - Build relationship between existing indicators and FU
  - Obtain specific information for SLCA analysis
  - Determine the indicators of SLCA
  - Quantify all impact factors
  - Evaluate results
Relationships of LCC, LCA, and SLCA

- LCSA is a combination of LCC, LCA, LCA, and SLCA with some linear/non-linear and static/dynamic features

“The combined impacts, positive and negative, of the sets of measures as a whole, are likely to be more than the simple sum of the impacts of their constituent measures because of synergistic effects.” – Lee and Kirkpatrik, 2001
Relationships of LCC, LCA, and SLCA

- LCC = F(LCA, SLCA)
- LCA = G(LCC, SLCA)
- SLCA = H(LCC, LCA)
Conclusions

- LCC Calculation

  - Cost Estimation
    - Initial capital costs
    - Life of asset
    - Discount rate
    - Disposal cost

  - Uncertainty Factors
    - Deicer usage frequency
    - Variation of operating time
    - Deicers demanding rate
    - Distribution
    - Discount rate
Conclusions

☐ LCA Analysis

- Necessary Steps
  - Goal and scope
  - Inventory analysis
  - Impact assessment
  - Interpretation

- Work Flow
  - Applied chemicals
  - Pavement type
  - Traffic
  - Climate
  - Etc.
Future Research

- Methods to quantify the indicators in each branch
- Challenges regarding the further investigation of LCA and SLCA analysis
- Exploration into the interactions between LCC, LCA, and SLCA
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Thank you!

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