Tier 1 UTC for Environmentally Sustainable Transportation in Cold Climates (CESTiCC)

Life-cycle Sustainability Assessment of Highway Winter Maintenance Operations (Phase I)

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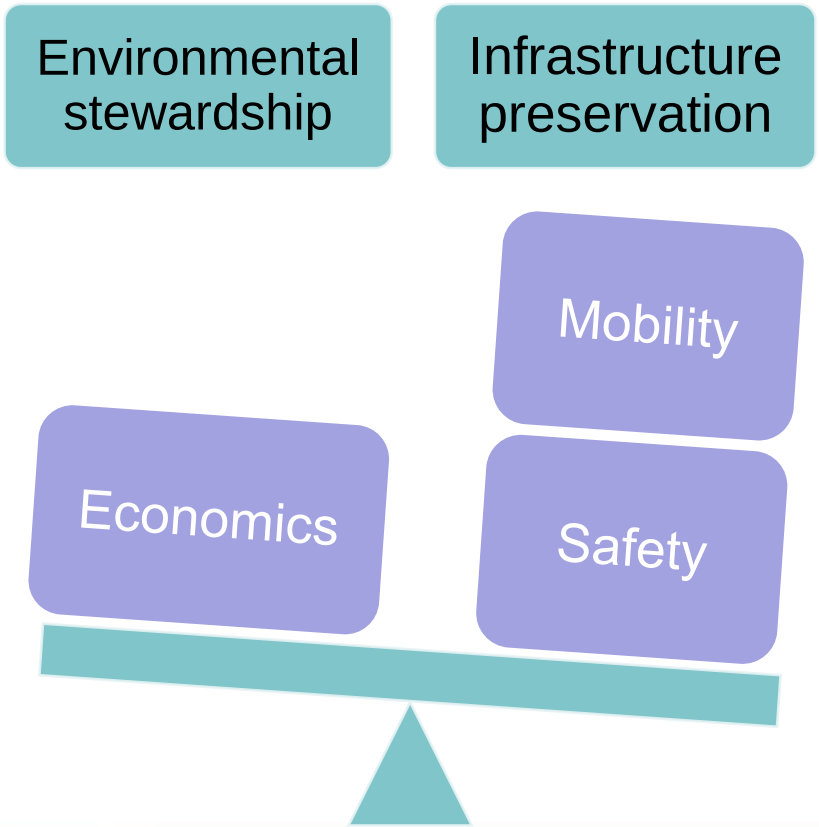
Overview

- Problem Statement
- Project Objective
- Work Plan
- Product and Timeline
- Task 1
- Task 2
- Plan of Task 3

Problem Statement

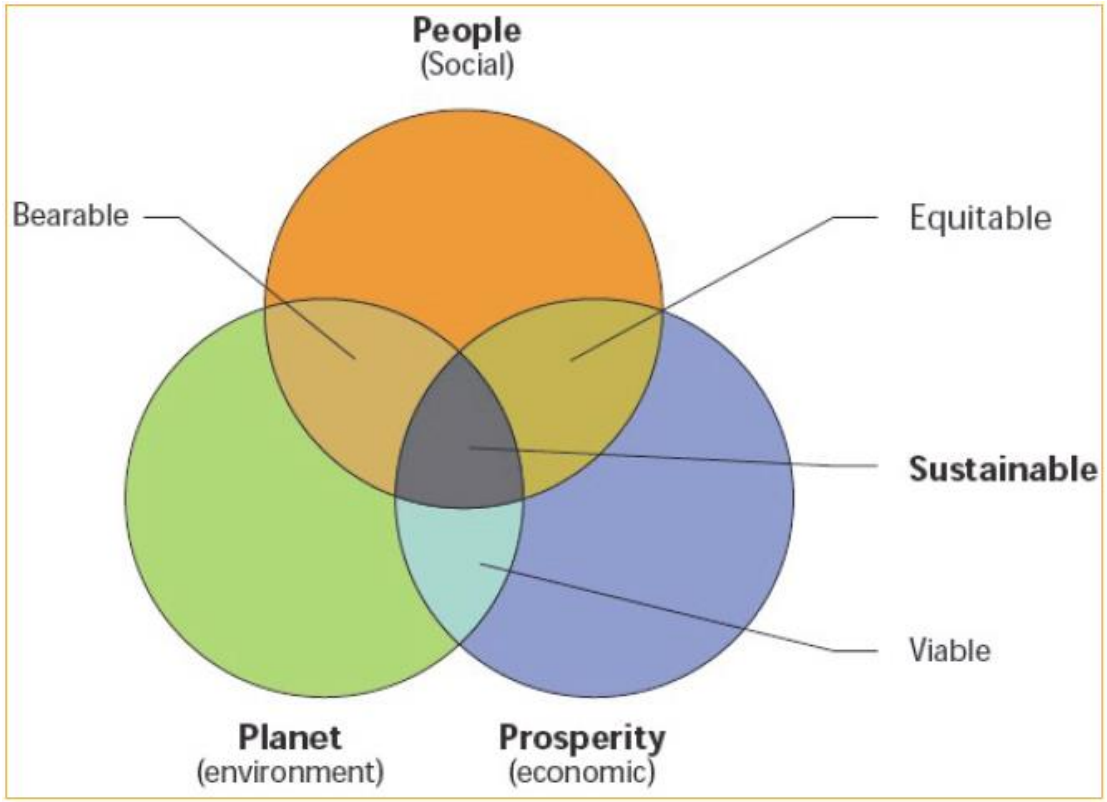
- Sustainability in highway winter maintenance has become a growing concern over the past decade

- Traditionally, nominal cost and effectiveness are the major criteria when selecting highway winter maintenance strategies
- Negative impacts
  - Infrastructure degradation
  - Automobile damage
  - Natural environment impact
  - Etc.



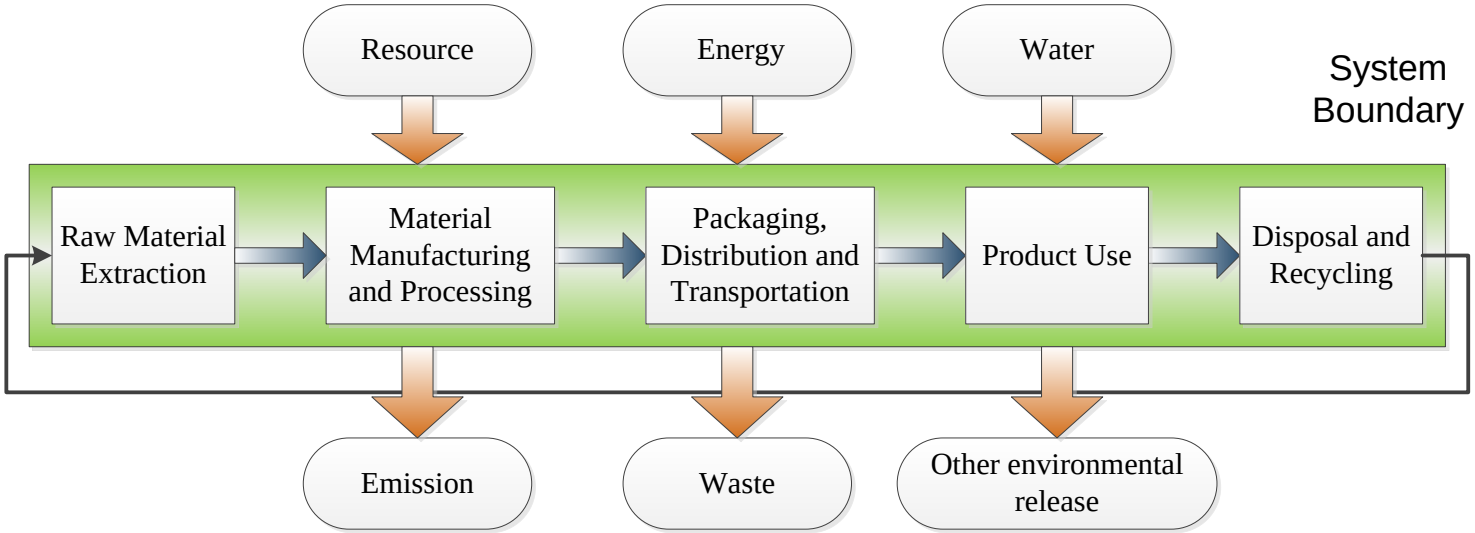
Problem Statement

- The principles of sustainability generally put emphasis on triple bottom lines: economy, society and environment



Problem Statement

- The production, distribution, storage, and application of these compounds are all contributing to the environmental footprint of highway winter operations



- It is important to consider the entire road-treatment life cycle in the development of a comprehensive sustainability assessment framework

Objective

- Develop a systemic life-cycle framework to enable comprehensive assessment of environmental sustainability of snow and ice control products used in winter highway operations
  - Provide the ability to evaluate the sustainability of chloride-based treatment through its entire life-cycle
  - Correlate winter maintenance sustainability to snow and ice control product type, treatment life-cycle, environmental impacts and social-economic costs and benefits
  - Provide reference and guidance for further sustainable winter maintenance exploration

Work Plan

- Task 1. Literature Review on Highway Winter Maintenance and Sustainability Accounting
- Task 2. Sustainability Accounting of Highway Winter Maintenance Operations
- Task 3. Development of Comprehensive Life-cycle Sustainability Assessment Framework
- Task 4. Final Report

Product and Timeline

- One paper for presentation at conference (e.g. TRB annual meeting) and publication in a peer-reviewed journal

	Month														
Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Literature review	X	X	X												
2. Sustainability accounting		X	X	X	X	X									
3. Framework development				X	X	X	X	X	X	X	X	X	X		
4. Final report												X	X	X	X
Deliverables/Milestones															
1. Quarterly report			X			X			X			X			
2. Draft final report													X		
3. Final report/manuscript															X

Task 1

- Definition of sustainability
- Sustainability assessment approaches in various industries
- Basic concepts related to life-cycle sustainability assessment
- Approaches of life-cycle sustainability assessment
- Review of highway winter maintenance operations

Definition of Sustainability

- Sustainability principles are beneficial to balance the objectives in transportation projects and programs; however, there is no standard definition for sustainable development.

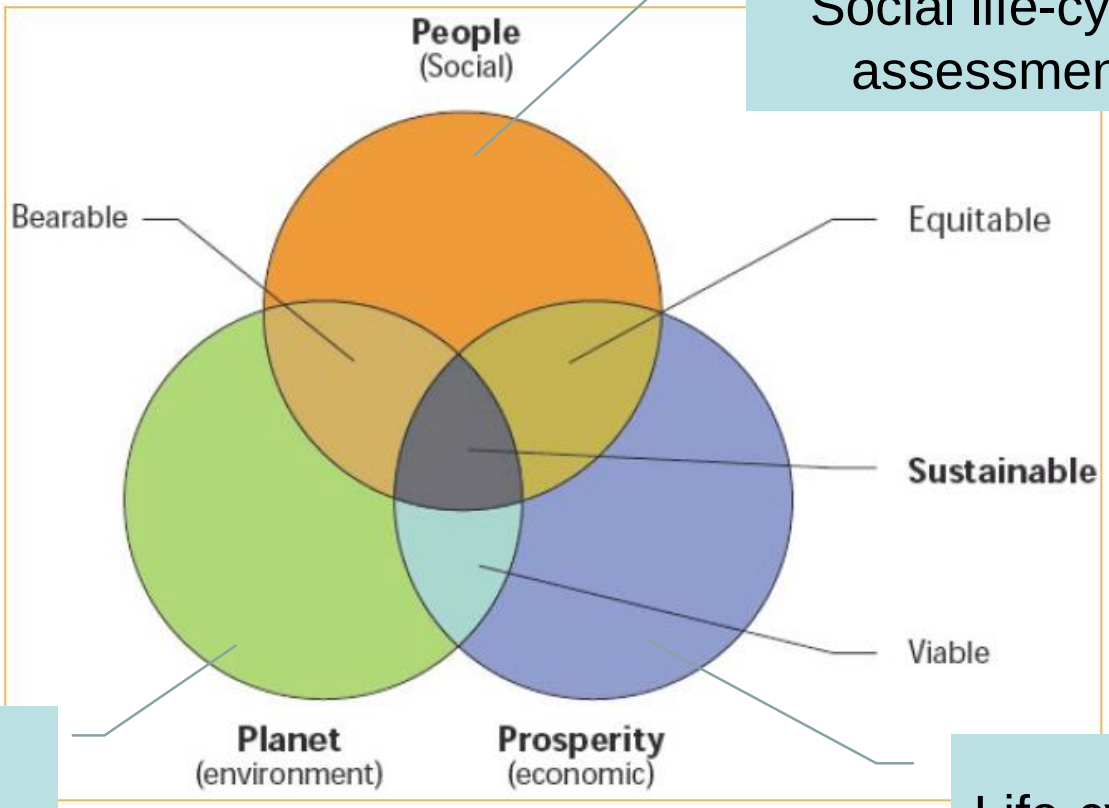
"*Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development, 1987).

"*The design of human and industrial systems to ensure that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health and the environment*." Mihelcic et al. (2003)

Sustainability Assessment Approach in Various Industries

- Global tool
  - Checklist
  - Life cycle analysis
  - Qualitative certification method (label)
  - Etc.
- Thematic tool
  - Greenhouse gasses emission evaluation
  - Carbon footprint evaluation
  - Energy consumption evaluation
  - Etc.
- Winter maintenance decision support tool

Life-Cycle Sustainability Assessment (LCSA)



Social life-cycle assessment

Life-cycle assessment

Life-cycle costing

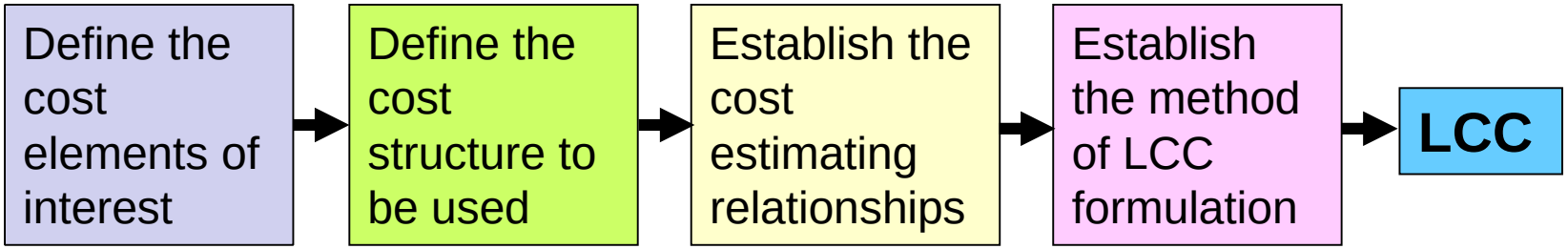
LCSA=LCC+LCA+SLCA

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



Harvey's life-cycle costing procedure

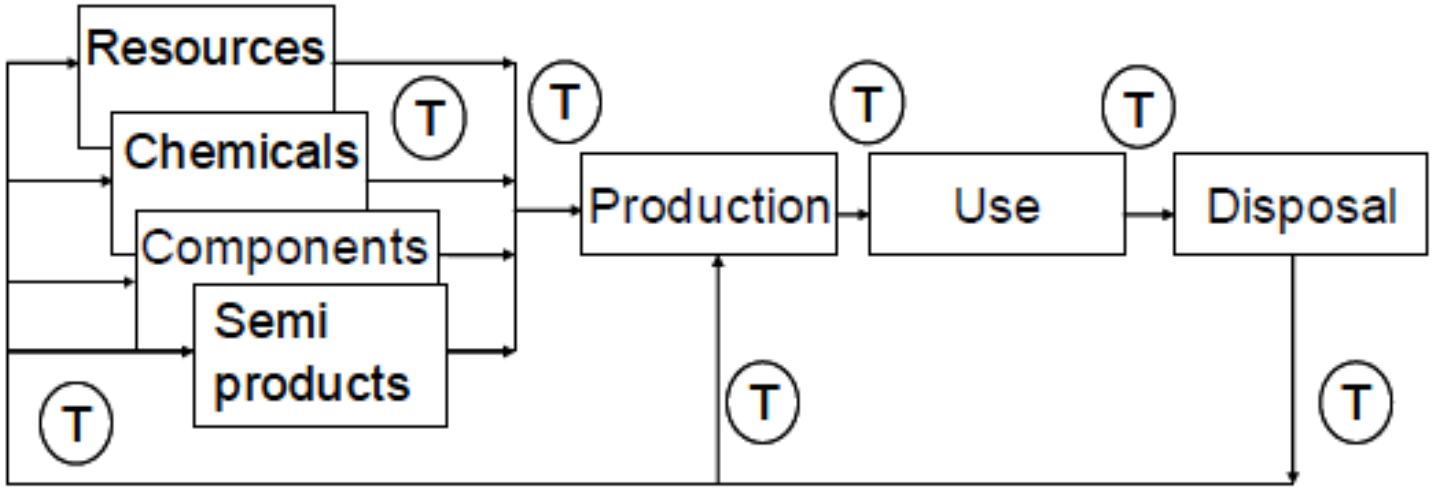
Element	Considerations	
Initial capital costs	• Purchase costs; • Acquisition/finance costs; • Installation/commissioning/training costs.	
Life of the asset	• Functional life • Physical life • Technological	• Economic life • Social and legal
Discount rate	Estimates vary between 3-4% and in excess of 20%	
Operating and maintenance costs	• Regular planned maintenance • Unplanned maintenance (responding to faults) • Intermittent maintenance (for major life refurbishment)	
Disposal cost	Incurred at the end of an asset's working life in disposing of the asset	
Information and feedback	• Failure rate and downtime forecast • Forecast spares requirements • Maintenance requirements • Annual maintenance cost forecast	
Uncertainty and sensitivity analysis	• Differences between the actual and expected system performance • Changes in operational assumptions • Future technological advances • Changes in the price levels of a major resource • Errors in estimating relationships, price rates and inflation rate	

Life-Cycle Assessment (LCA)

- Concept

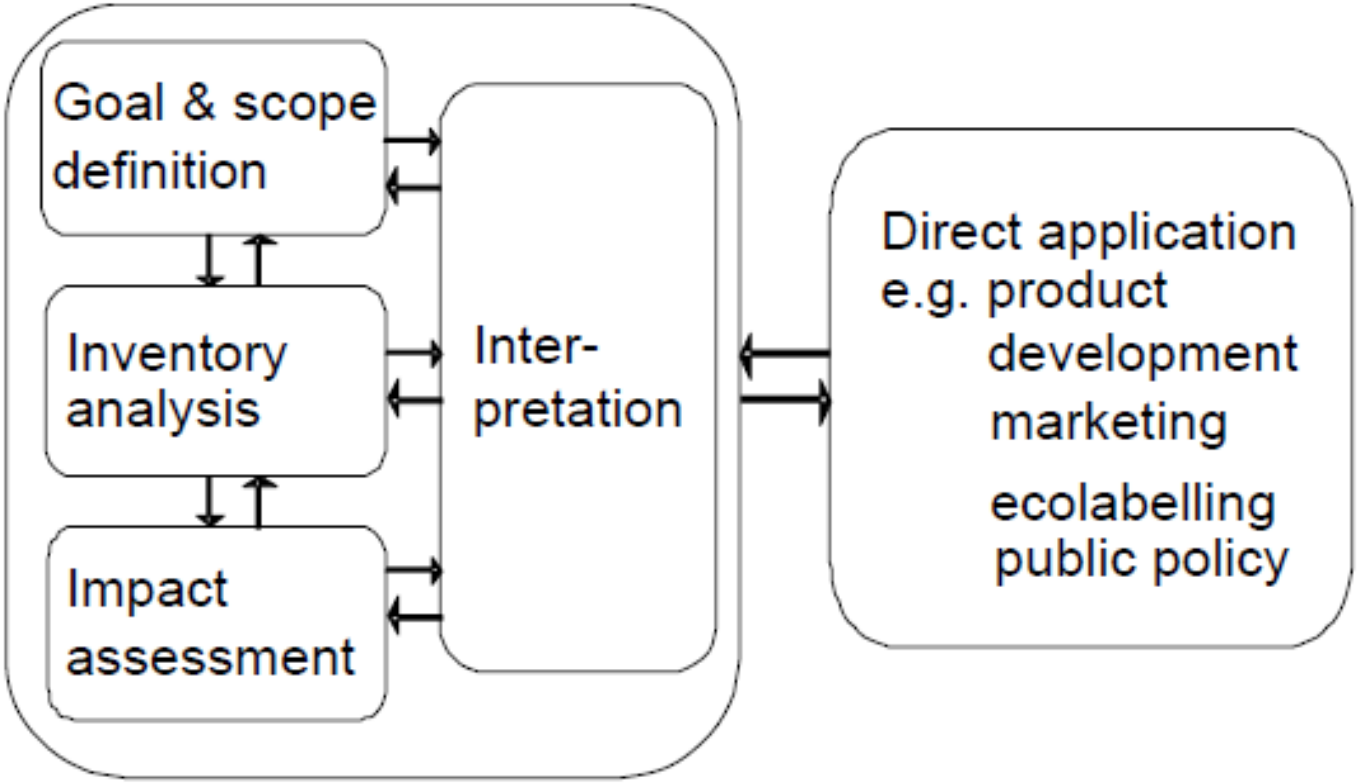
  The compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (Handbook on life-cycle assessment, Guinee, 2004)

- Procedure



Life-cycle of a product, where transportation processes (circumscribed T)

LCA Approach



The framework of LCA according to the ISO 14040 standard

Social Life-cycle Assessment (SLCA)

- Concept

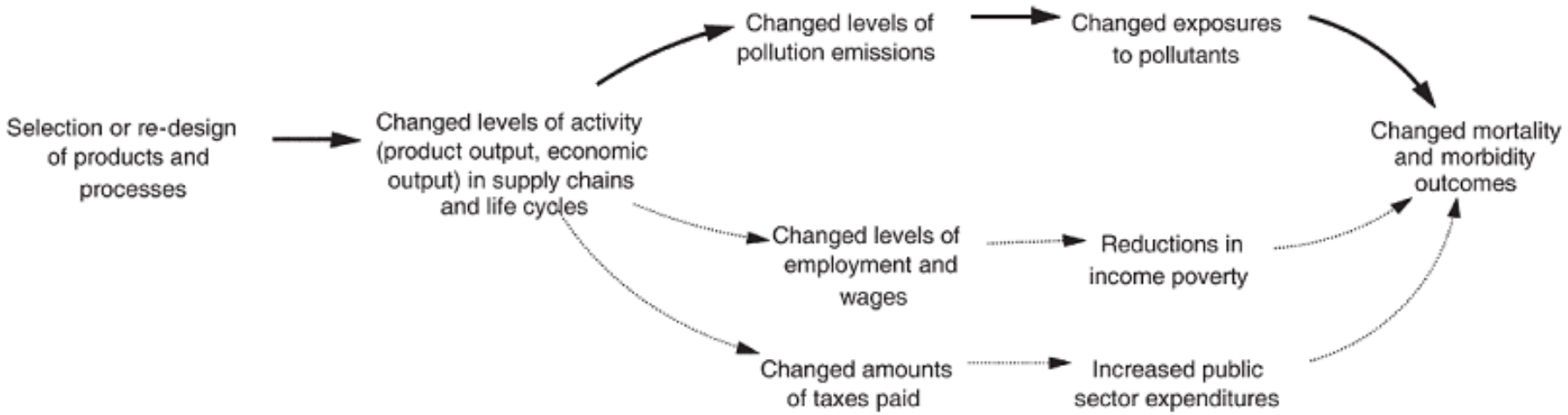
In the SETAC Workshop Report, it was claimed that the social welfare impact category was "… *the primary emphasis should be on environmental impacts that arise directly or indirectly from other social impacts …*" The proposed social impact category called for a more comprehensive discussion among LCA methodology developers (UNEP/SETAC 2009).

In 2006, social scientists introduced the socioeconomic indicators for the application of SLCA, including *human rights, labor practices, decent working conditions, and product responsibilities*. These factors are directly affiliated with a stakeholder of the corresponding product system

SLCA Approach

- The SLCA is focused on the social activities' effects on human beings, as a result, how to quantify the social impacts became a hard topic.

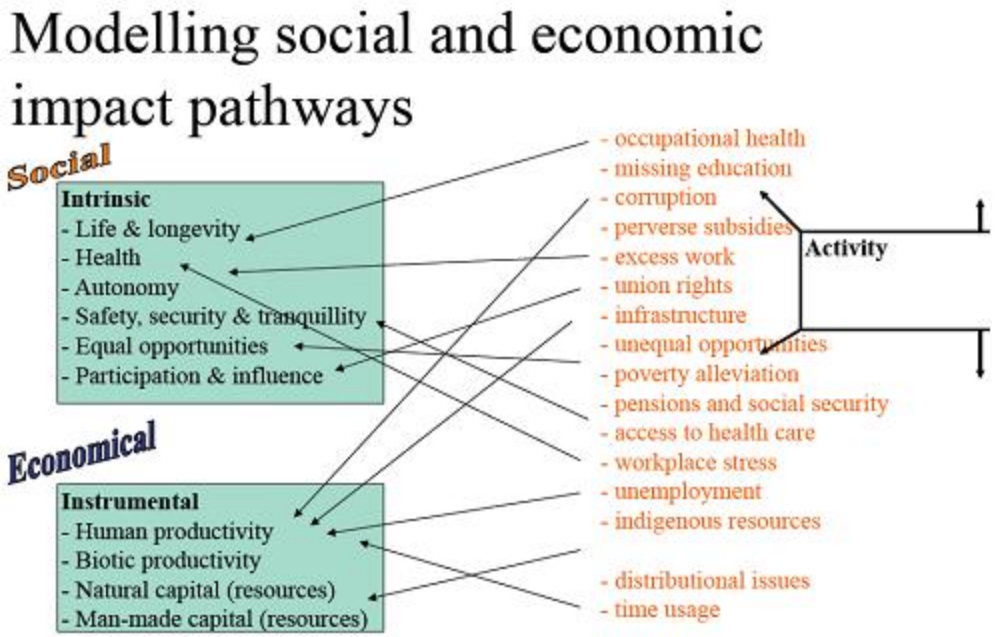
- Norris's Approach

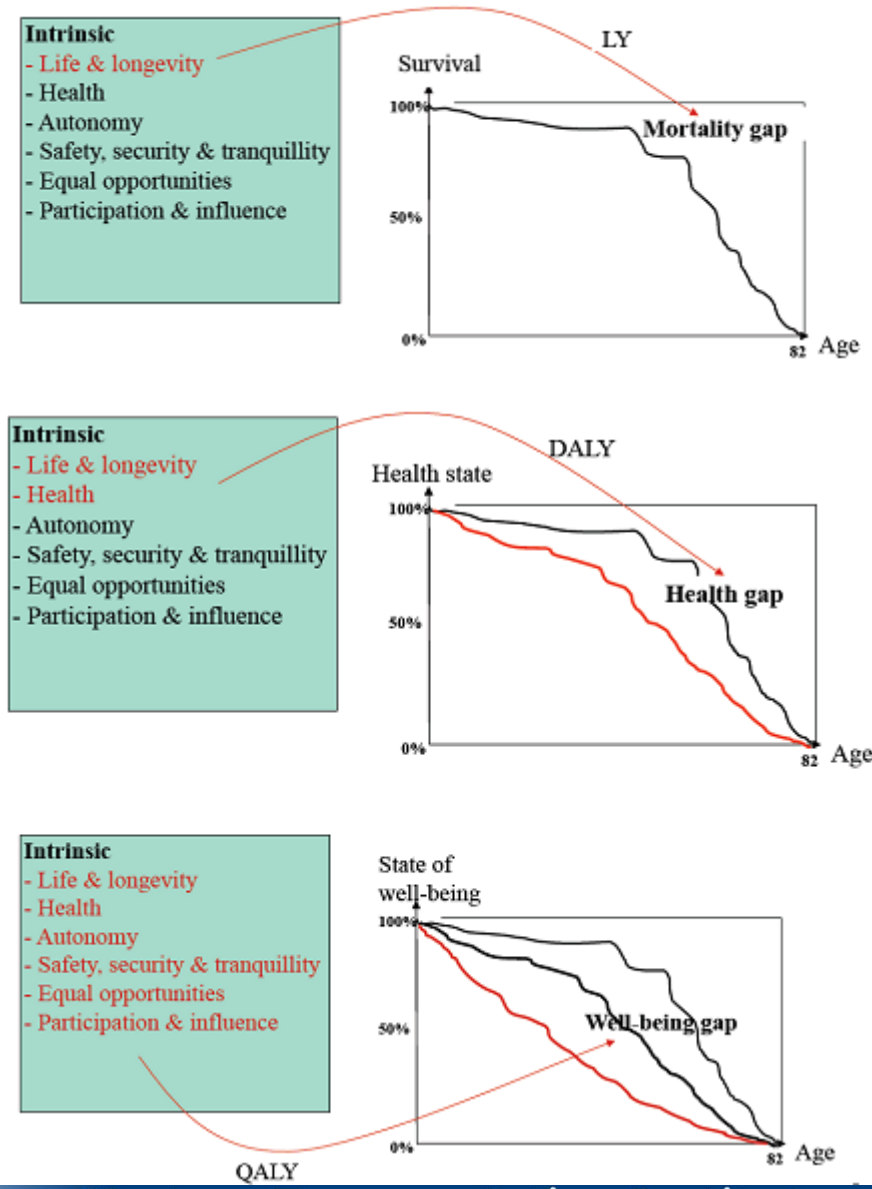


- Norris developed an endpoint approach to give the health impact of a product from a life cycle perspective which demonstrates the effects of the product life cycles on human-health

SLCA Approach

- Weidema's Approach





- The social impact is focused on human health which was measured by using human longevity as indicator.

Highway Winter Maintenance Operations

- Anti-icing/deicing chemicals
  - NaCl, MgCl2, CaCl2, KAc...
- Physical modification pavement surface
  - Flexible pavement, polymer overlays, Safelane…
- Snow plowing or sanding
- Asphalt pavement with anti-icing additives
  - Mixing with asphalt binder…
- Heated pavement technologies
  - Pipeline, electrical heating (overlay and whole pavement heating)
- Fixed Automated Spray Technology (FAST)

Task 2

- Benefits and negative impacts of winter maintenance operations
- Sustainability accounting of typical winter maintenance operations in three pillars
  - Anti-icing/deicing chemicals
  - Physical modification pavement surface
  - Snow plowing
  - Asphalt pavement with anti-icing additives
  - Heated pavement technologies
  - Fixed Automated Spray Technology (FAST)

Sustainability Accounting of Highway Winter Maintenance Operations

Positive impacts of winter maintenance operations

- Safety enhancement
- High transport efficiency

- Sustain ice free roads for a longer period of time than with use of sand
- Return roads to bare conditions rapidly
- Reduce time and personnel needed for removal of snow and ice
- Keep roads wet longer during heavy storm events
- Effective in melting black ice
- Minimize the need for sand, thereby improving air quality
- Greatly increase ease of traffic movement on the highways
- Increase the level of service that CDOT can provide
- Make the highways safer for motorists.

Sustainability Accounting of Highway Winter Maintenance Operations

Positive impacts of winter maintenance operations

- Safety enhancement
- High transport efficiency

Social Benefits

- Lives saved in reduced traffic accidents
- Lives saved in reduced response time to medical emergencies

Economic Benefits

- Energy savings in fuel costs
- Reduced wage loss from work absenteeism
- Reduced production losses
- Reduced delays in shipment of goods

Sustainability Accounting of Highway Winter Maintenance Operations

Negative impacts of winter maintenance operations

- Anti-icing/deicing chemicals
  Pollution to the environment, corrosion to the infrastructures, corrosion to the vehicles
- Physical modification pavement surface
  Increase investment cost,
- Snow plowing
  Labor hours, low efficiency,
- Asphalt pavement with anti-icing additives
  Not effective, corrosion to the infrastructures, environmental pollution,
- Heated pavement technologies
  Expansive, huge energy consumption
- Fixed Automated Spray Technology (FAST)
  High installation cost, device cost, corrosion to the infrastructures and vehicles.

Anti-icing/Deicing Chemicals

LCC

Direct cost of deicers, negative impacts on infrastructures, the discount rate, operating and maintenance cost, disposal cost, information and feedback, and uncertainty and sensitivity analysis

LCA

Inventory analysis (*database development, tools for modeling, and input-output analysis*), impact assessment (resources, land use, water, toxicity, air, normalization, and weighting)

SLCA

Labors, human rights, work condition, health and safety, contribution to economy

Physical Modification Pavement Surface

Rough surfaces, physical bending of pavements, or High friction anti-icing polymer based overlays

LCC

Discount rate, operating and maintenance cost, disposal cost, information and feedback, and uncertainty and sensitivity analysis

LCA

Inventory analysis (*database development, tools for modeling, and input-output analysis*), impact assessment (resources, land use, toxicity, normalization, and weighting)

SLCA

Labors, human rights, work condition, health and safety, contribution to economy

Snow Plowing or Sanding

LCC

Material cost, equipment cost, operating and maintenance cost, disposal cost, discount rate, information and feedback, and uncertainty and sensitivity analysis

LCA

Inventory analysis (*database development, tools for modeling, and input-output analysis*), impact assessment (resources, land use, water, air, normalization, and weighting)

SLCA

Labors, human rights, work condition, health and safety, contribution to economy

Asphalt Pavement with Anti-icing Additives

LCC

Direct cost of deicers, negative impacts on infrastructures, the discount rate, operating and maintenance cost, disposal cost, information and feedback, and uncertainty and sensitivity analysis

LCA

Inventory analysis (*database development, tools for modeling, and input-output analysis*), impact assessment (resources, land use, water, toxicity, air, normalization, and weighting)

SLCA

Labors, human rights, work condition, health and safety, contribution to economy

Heated Pavement Technology

LCC

Energy consumption, installation cost, the discount rate, operating and maintenance cost, disposal cost, information and feedback, and uncertainty and sensitivity analysis

LCA

Inventory analysis (*database development, tools for modeling, and input-output analysis*), impact assessment (resources, land use, water, normalization, and weighting)

SLCA

Labors, human rights, work condition, health and safety, contribution to economy

Fixed Automated Spray Technology (FAST)

LCC

Direct cost of deicers, installation cost, negative impacts on infrastructures, the discount rate, operating and maintenance cost, disposal cost, information and feedback, and uncertainty and sensitivity analysis

LCA

Inventory analysis (*database development, tools for modeling, and input-output analysis*), impact assessment (resources, land use, water, toxicity, air, normalization, and weighting)

SLCA

Labors, human rights, work condition, health and safety, contribution to economy,

Plan of Task 3

- Drawing upon the sustainability accounting analysis from Task 2, develop a general life-cycle sustainability assessment framework for winter maintenance operations

- Case study
  - Such as comparison of two different winter maintenance strategies

Tier 1 UTC for Environmentally Sustainable Transportation in Cold Climates (CESTiCC)

Life-cycle Sustainability Assessment of Highway Winter Maintenance Operations (Phase I)

Thank you!

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Life-cycle Costing (LCC)

Define the cost elements of interest	Include all expenditure from acquisition until disposal at the end of its life.
Define the cost structure to be used	Involve grouping costs to identify potential trade-offs so as to achieve optimum LCC.
Establish the cost estimating relationships	Mathematical expression is used to describe, for estimating purposes, the cost of an item or activity as a function of one or more independent variables.
Establish the method of LCC formulation	Involve choosing an appropriate methodology to evaluate the asset's LCC.

LCC Approach

- The objective of life cycle costing (Royal Institute of Chartered Surveyors)
  - To enable investment options to be more effectively evaluated
  - To consider the impact of all costs rather than only initial capital costs
  - To assist in the effective management of completed buildings and projects
  - To facilitate choice between competing alternative

- In order to achieve these objectives the following elements of LCC have been identified:
  - Initial capital costs
  - Life of the asset
  - The discount rate
  - Operating and maintenance costs
  - Disposal cost
  - Information and feedback
  - Uncertainty and sensitivity analysis

LCA Approach

- A life cycle assessment in accordance with the ISO 14040 standard proceeds iteratively through four phases.

Phase	Purpose
Goal and scope definition	Define the goal and intended use of the LCA and scope assessment in terms of boundaries of the product system
Life cycle inventory analysis (LCI)	Collect information on the input and output (environmental exchanges) for all the processes within the boundaries of the product system
Life cycle impact assessment (LCIA)	Translate the environmental burdens quantified in LCI into the related potential environmental impacts (or category indicators)
Interpretation	Analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of LCI and/or LCIA

Impact Categories and indicators at midpoint level

Human rights
Non-discrimination, including indicators on diversity, such as composition of employees on all levels according to gender, age group, disabled, part-time workers and other measures of diversity
Freedom of association and collective bargaining
Child labor, including hazardous child labor
Forced and compulsory labor

Labor practices and decent work conditions
Wages, including equal remuneration on diverse groups, regular payment, length and seasonality of work ad minimum wages
Benefits, including family support for basic commodities and workforce facilities
Physical working conditions, including rates of injury and fatalities, nuisances, basal facilities and distance to workplace
Training and education of employees

Impact Categories and indicators at midpoint level

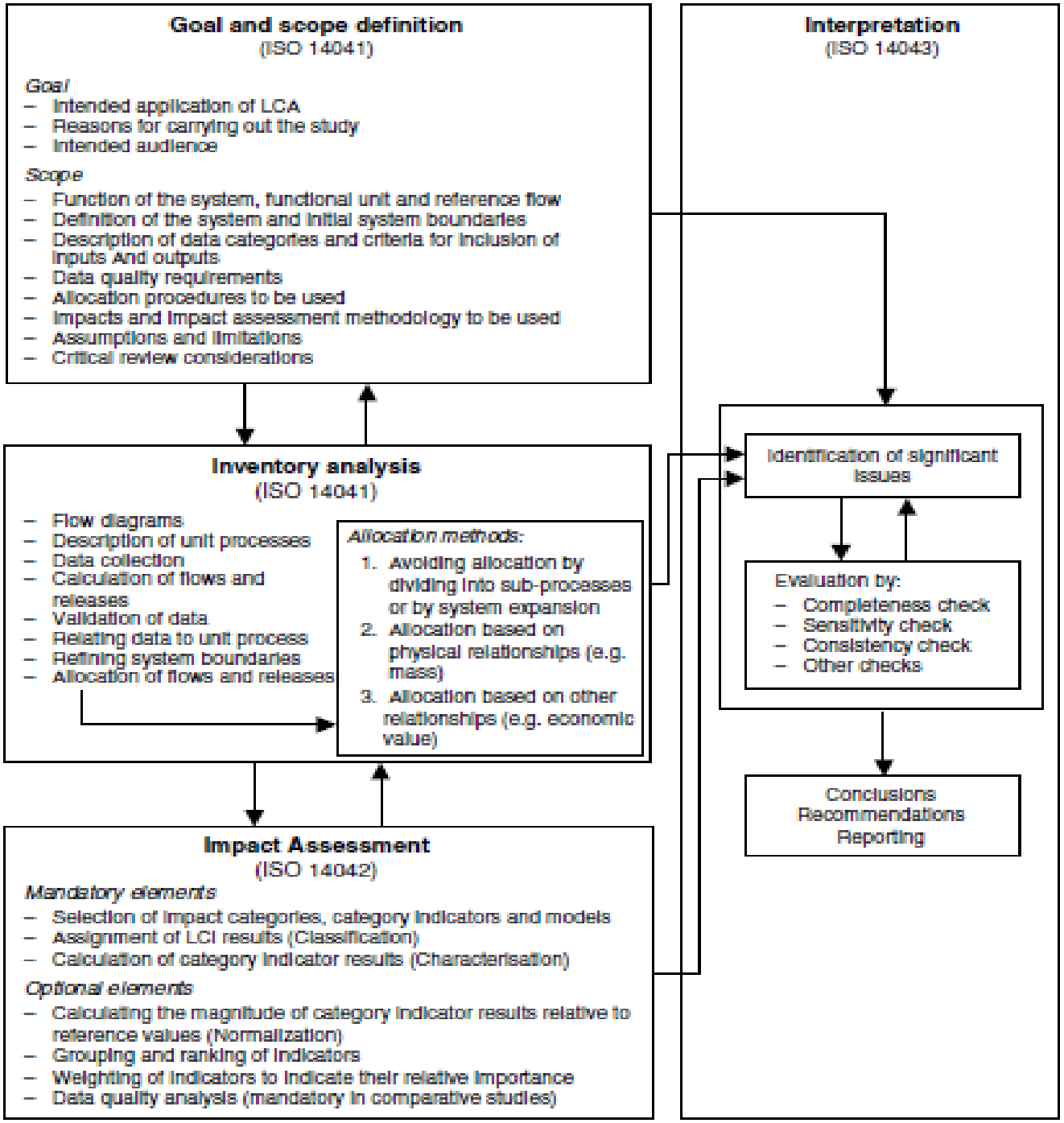
Society
Corruption, including incident/press reports concerning fraud, corruption and illegal price-fixing, and violation of property rights.
Development support and positive actions towards society
Local community acceptance, such as complaints from society and presence of communication channels
Ensuring of commitment to sustainability issues from and towards business partners

Product responsibility
Integration of costumer health and safety concerns in product, such as content of contaminants/nutrients, other threats/benefits to human health due to product use, and complaint handing system
Information about product to users, such as labelling, information about ingredients, origin, use, potential dangers and side effects
Marketing communications, such as ethical guidelines for advertisements

Impact Categories and indicators at endpoint level

- Mortality
- Morbidity
- Autonomy
- Safety, security and tranquility
- Unequal opportunities
- Participation and influence

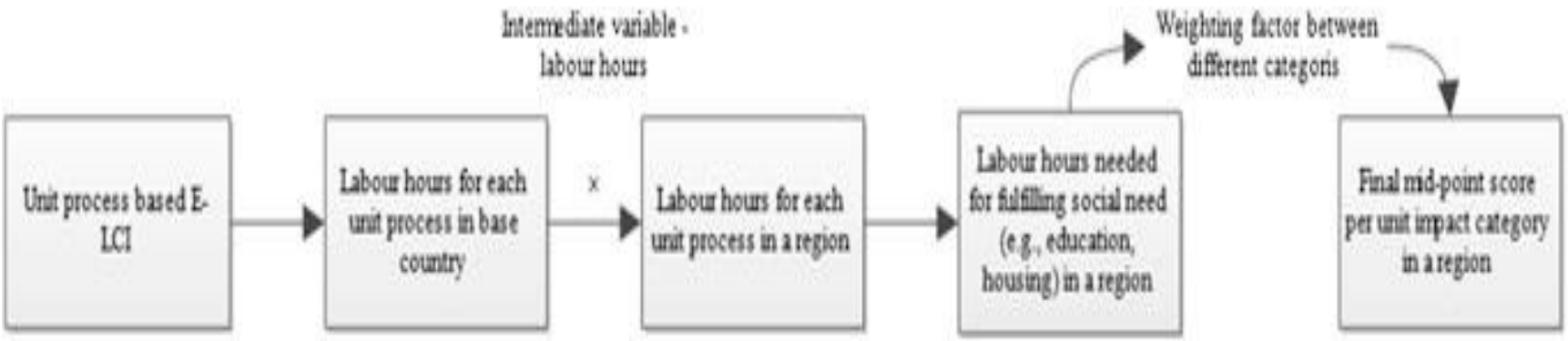
LCA Approach



MONTANA STATE UNIVERSITY

SLCA Approach

- Hunkeler's Approach
  - Collect the data of material usage and emission in a product's life cycle
  - Estimate employment hours for a country in material extraction, production, and emission management of material usage and emission
  - Estimate employment hours for every country in a product's life cycle
  - Estimate the purchasing ability for a person working one hour in every country
  - Estimate the total purchasing ability for each country from working for the product in its life cycle



Sustainability Accounting of Highway Winter Maintenance Operations

Life-cycle sustainability assessment of winter maintenance operations from economic, environmental, and social perspectives

- **Negative impacts of winter maintenance operations**
  - Environment (water, soil, air, vegetation, wildlife, etc.)
  - Corrosion to the infrastructures
  - Corrosion to the vehicles
  - Human health