Assessment Methodologies for ITS Solutions

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Outline

1 Introduction
2 Assessment and decision making
3 ITS and related effects
4 Modeling Transportation Systems
5 Impact Assessment
6 Comparison of alternatives
1. Introduction

Assessment of ITS solutions

Definition

The “art of evaluating” transportation projects and programs for:

- Decision Making
- Design
- Performances appraisal
- Monitoring
1. introduction

Assessment of ITS solutions
Similarities and Differences with transportation planning

ITS Solutions

IDEA
PLAN
PROTOTYPE
PILOT TEST
LARGE-SCALE DEMOS
FULL-SCALE IMPLEMENTATION

Checklist
Delphi
Simulation and Models
Laboratory tests
Field trials
Impact monitoring and Simulation/Models

Taken from lecture “Introduction to the Assessment of ITS Measures” by K. El-Araby

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1. introduction

Assessment of ITS solutions
Similarities and Differences with transportation planning

Infrastructure/Services projects

PLAN
FEASIBILITY STUDIES
DESIGN
BUILDING
OPERATION

Simulation and Models
Design and Reconnaissance
Simulation and Models

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2. assessment and decision making

**Rational Decision Making in the ITS era**

**Multiple Decision Makers and Stakeholders**

**Public Administrations**
- Local
- Regional
- National
- International

**Operators**
- Transport Infrastructures Operators
- Transport Services Operators
- ITS providers, ...

**Community**
- Transport Users
- Residents
- Shoppers, ...
2. assessment and decision making

Rational Decision Making in the ITS era

Rationality: Acting in the best possible way considering the aim
(Elster, 1986)

Minimal Requirements of Rational decisions:

- **consistent**
  - internally w. r. t. the objectives and externally with other decisions (plans, projects)

- **comparative**
  - considering one or more alternatives (e.g. not deciding, one of the available options, searching for other possibilities)

- **aware**
  - sufficient information about the options (features), the context (physical and decisional) and other related choices (internal, horizontal and vertical coherence)
  - sufficient information about the effects of the options (costs, benefits, risks and opportunities)

- **flexible**
  - amenable to changes due to
    - new information on the alternative options and their effects
    - context changes (economic, physical, institutional)
    - Decision “opportunity costs” (postpone unnecessary decisions)

Rational Decision Making in the ITS era
ITS solutions are only “tools” to reach objectives often conflicting

**Stated**
- To Improve mobility (Performances)
- To Reduce production costs (Efficiency)
- To Reduce users generalized costs (Quality)
- To improve public health (i.e. harmful pollutants, road safety, …)
- To reduce environmental impacts (i.e. gas emissions, visual intrusion in the surrounding landscape, …)
- To reduce territorial inequalities and class disparities (Equity)
- To foster territorial development (redevelopment areas, new districts, …)
- To boost economic growth
- To enlarge public consensus upon decisions

**Unstated**
- To make a case for ITS
- To enlarge political consensus
- To legitimate public role
- To maximize private profit
- To expand markets

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2. assessment and decision making

Rational Decision Making in the ITS era
Potential “false friends”

If the tool works, but the policy does not, the tool can be discredited!!

e.g. PT reserved lanes and preferential traffic control in urban networks causing excessive delays to cars

2. assessment and decision making

Limited Rationality and Public Engagement Framework

DECISIONAL CONTEXT
ANALYSIS OF INITIAL CONDITIONS
- Activity system
- Transportation system
DEFINITION OF OBJECTIVES, CONSTRAINTS, AND FIELD OF INTERVENTION
FORMULATION OF ALTERNATIVE PROJECTS (PLANS)
SIMULATION AND EVALUATION OF THE EFFECTS/IMPACTS
COMPARISON AMONG ALTERNATIVES
DECISION MAKING

STAKEHOLDERS IDENTIFICATION
LISTENING
INFORMATION, COMMUNICATION AND CONSULTING
MONITORING
PILOT/FULL IMPLEMENTATION

SHARED AND ROBUST CONSENSUS?
YES
NO

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3. ITS and related effects

ITS solutions

A (not exhaustive) classification based on the type of system

- Advanced Travelers Information Systems (ATIS), e.g.
  - VMS
  - Route and parking guidance
  - Public Transportation Information, etc.

- Advanced Driver Assistance Systems (ADAS), e.g.
  - Adaptive Cruise Control
  - Collision Warning/Assistance
  - ABS, etc.

- Advanced Traffic Management Systems (ATMS), e.g.
  - Actuated Control, Coordinated Control
  - Ramp metering, Lane management, Speed Control, etc.
  - Prioritization, Route clearance, etc.

- Advanced Travel Demand Management (ATDM), e.g.
  - congestion charge, eco-pricing, tolling system, mobility credits, etc.
3. ITS and related effects

ITS solutions

Classification based on the degree of change in users response

- **Performance optimization of existing systems**, e.g.
  - *Private Transport*: Traffic Lights, Ramp Metering, Lane Management, Variable Speed Limits, V2V and V2I communication systems
  - *Public Transport*: AVM, Priority Light Control
  - *Rail Transport*: ERTMS/ETCS

- **Infomobility**, e.g. user-oriented traffic and travel information systems (ATIS), Pre-Trip, En-Route, etc.

- **Control and Enforcement**, e.g. speed enforcement, limited access, etc.

- **Implementation of policies**, e.g. congestion charge, eco-pricing, tolling system, mobility credits, Limited Traffic Zones, etc.

CHANGE IN USERS/SYSTEM RESPONSE

NEEDS FOR PUBLIC ENGAGEMENT

ITS solutions

Classification of the impacts (variation between two states)

To understand and evaluate ITS impacts, we have to understand and simulate transportation systems

short-term effects

long-term effects
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outline

1. Introduction
2. Assessment and decision making
3. ITS and related effects
4. Modeling Transportation Systems
5. Impact Assessment
6. Comparison of alternatives

4. modeling transportation systems

- ITS SOLUTION
- TRANSPORTATION FACILITIES, SERVICES, VEHICLES AND TECHNOLOGY
- TRANSPORTATION SERVICE PERFORMANCE
- SUPPLY ELEMENT CAPACITIES
- CONGESTION
- FLOWS ON MODAL NETWORKS
- TRAVEL DEMAND BY TRANSPORTATION MODE
- LEVEL, SPATIAL AND TIME PATTERNS OF TRAVEL DEMAND
- DEMAND
- ACCESSIBILITY active passive
- LEVEL AND LOCATION OF ECONOMIC ACTIVITIES
- NUMBER AND LOCATION OF HOUSEHOLDS BY TYPE
- SPACE AVAILABILITY BY AREA AND TYPE

ACTIVITY SYSTEM

TRANSPORTATION SYSTEM
4. modeling transportation systems

**Alternative assumptions in transp. systems simulation**

*Levels of representation*

- **Time representation**
  
  - Within-day static
  
  - Within-day dynamic

- **Space representation**
  
  - Continuous
  
  - Discrete

- **Users representation**
  
  - Continuous fluid
  
  - Discrete units

- **Users response**
  
  - Driving behaviors (car-following, lane changing, merging, look-ahead, etc.)
  
  - Route choices (pre-route, en-route, etc.)
  
  - Other demand dimensions
4. modeling transportation systems

Supply models for road systems

Levels of detail

<table>
<thead>
<tr>
<th>FLOW REPRESENTATION</th>
<th>PERFORMANCE FUNCTIONS</th>
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<td>AGGREGATE (explicit capacity)</td>
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<tr>
<td>CONTINUOUS</td>
<td>MACRO-SIMULATION</td>
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<tr>
<td></td>
<td>SPACE DISCRETE</td>
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<tr>
<td>DISCRETE</td>
<td>MESO-SIMULATION</td>
</tr>
</tbody>
</table>

4. modeling transportation systems

Demand models

Choice dimensions

Travel demand is the result of travelers’ choice behavior over several dimensions, e.g.

- Outer (w.r.t. assignment)
  - activity participation
  - trip frequency
  - activity time
  - destination
  - mode/service

- Inner (w.r.t. assignment)
  - driver behaviour
  - departure time
  - path choice/adjustment

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4. modeling transportation systems

Demand models

*Path choice* $p(k/o,d)$

**DETERMINISTIC:** Users choose only minimum generalized cost alternatives

**PROBABILISTIC:** Users may choose any available alternative with a probability depending on generalized costs

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4. modeling transportation systems

Demand models – **DAY-TO-DAY VARIABILITY**

- Modeling past experience (learning)  ➔  Cost updating model
- Modeling (pre-trip /en-route) combination of different sources of Information  ➔  Information combination model
- Modeling choice updating (including inertia)  ➔  Choice updating model
4. modeling transportation systems

Assignment models

Definition of congestion

The dependence of users’ perceived network performances on users’ flows

- Travel Times (average, reliability)
- Driving experience (number of stops, driving effort, etc.)
- Monetary cost (fuel, tolls, etc.)

E.g. motorway links

\[ tr_a(f_a) = \frac{L_l}{v_{0l}} + \gamma \left( \frac{L_l}{v_{cl}} - \frac{L_l}{v_{0l}} \right) \left( \frac{f_a}{Q_l} \right)^{\gamma_2} \]

where:
- \( L_l \) is the length of link \( l \);
- \( v_{0l} \) is the free-flow average speed;
- \( v_{cl} \) is the average speed with flow equal to capacity;
- \( Q_l \) is the link capacity, i.e. the average maximum number of equivalent vehicles that can travel along the road section in a time unit. Capacity is usually obtained as the product of the number of lanes on the link \( N_l \) and lane capacity, \( Q_{ul} \);
- \( \gamma_1, \gamma_2 \) parameters of the function.
4. modeling transportation systems

Assignment models – NOT CONGESTED NETWORK

**Specification**

- **Demand Model**
  - OD demand flows
  - Path/Departure time choice model
  - Path flows
  - Path cost

- **Supply Model**
  - Link flows
  - Link costs
  - Link performances model

**Network Flow Propagation Model**

**Path Flows**

**Path Performances Model**

**Equilibrium**

**Dynamic Process (No ATIS)**

4. modeling transportation systems

Assignment models – CONGESTED NETWORK

**Specification**

- **Demand Model**
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**Network Flow Propagation Model**

**Path Flows**

**Path Performances Model**

**Equilibrium**

**Dynamic Process (No ATIS)**
4. modeling transportation systems

Transit Systems

*Difference w. r. t. road systems*
- Discrete space (stations, stops)
- Discrete time (service availability)

Transit Models

- **Frequency-based** approaches
  - line-based representation of services timetables
  - modal choice and path choice models depend on the line service frequency
  - assignment models that give the average flow of each line

- **Schedule-based** approaches
  - run-based supply models with explicit representation of services timetables
  - modal choice and path choice models depend on the run attributes
  - assignment models that give the average flow of each run

**Supply models – Line-based vs. Run-based**
4. modeling transportation systems

Transit Models
Demand models - Approaches

✓ Frequency-based approach
  • for **High-frequency** services

✓ Schedule-based approach
  • for **High-frequency** services
  • for **Low-frequency** services

<table>
<thead>
<tr>
<th>Frequency</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irregular Service</td>
<td>URBAN</td>
<td></td>
</tr>
<tr>
<td>Regular Service</td>
<td>REGIONAL</td>
<td>INTERCITY</td>
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ITS solutions
Effects on the transportation system

<table>
<thead>
<tr>
<th>ITS SOLUTIONS</th>
<th>INTERNAL EFFECTS (i.e. on the transportation system)</th>
<th>LEVEL OF DETAIL IN MODELING AND SIMULATION</th>
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<tbody>
<tr>
<td>Performance optimization of existing systems</td>
<td>Driver behavior Route choices</td>
<td>Microscopic traffic models Meso-Macro assignment</td>
</tr>
<tr>
<td>Infomobility</td>
<td>Adaptive route and trip strategies</td>
<td>Mesoscopic simulation</td>
</tr>
<tr>
<td>Control and Enforcement</td>
<td><strong>Depending on the strategy</strong></td>
<td><strong>Depending on the strategy</strong></td>
</tr>
<tr>
<td>Implementation of policies</td>
<td>Travel demand Route choices</td>
<td>Meso-macro assignment</td>
</tr>
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</table>
4. modeling transportation systems

Additional references

outline

1 Introduction
2 Assessment and decision making
3 ITS and related effects
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5 Impact Assessment
6 Comparison of alternatives
5. impact assessment

ITS solutions
Classification of the impacts (variation between two states)

Internal impacts

- Perceived by the users
- Not perceived by the users
- System operators

External impacts

- Population levels
- Residents' location
- Activity locations
- Activity levels

Pollutant emissions
Noise impacts
Visual intrusion
Environment

Short-term effects
Long-term effects

5. impact assessment

Impacts evaluation
Categories and common impact indices

Internal effects on:

- Transport users
  Direct variations of system performances (travel times reliability), variation of system capacity, variation of surplus, etc.

- Other travelers
  Indirect variations of the system performances, etc.

- System operators
  Variations in Operating Cost, Revenues, Investments, Net Present Value, Discounted Cash Flow, Return On Investment, etc.
5. impact assessment

Impacts evaluation
Categories and common impact indices

Externalities on:

- Safety
  Variation of the number of total/mortal/injury crashes per year, etc.

- Environment
  Variation of ton/yr of CO₂ equivalent, variation of the level of noise in dB(A), variation of the level of visual insertion on the landscape, etc.

- Territorial and Activity systems
  Variation of zonal accessibility, variation of the dispersion of generalized cost between different zones or different socio-economic categories, variation of the LOS of target zones, variation of housing and commercial activities density in target zones, variation of the number of available jobs, etc.

5. impact assessment

Impacts assessment for:

- Design and Evaluation (ex-ante)
  Inputs from Models/Simulation

- Monitoring (ex-post)
  Inputs from direct measures and Models/Simulation
5. impact assessment

ITS solutions

Classification of the impacts (variation between two states)

5. impact assessment

Impacts evaluation

Internal effects on transport users

Variation of the net perceived utility (surplus) related to the changes in the mobility choices between the ITS (P) and the no-ITS (NP) scenarios

- Behavioral approach
- Descriptive approach
5. impact assessment

Impacts evaluation
Internal effects on transport users

- Behavioral approach

Utility $U^i_p$ perceived by the user class $i$, located in $o$, for each potential trip
E.g. choice sequence $(x, o, d, m, k)$, in the state $P$ of the system, is expressed by:

$$U^i_p = \sum \beta_k X^i_{kj(i)} + \epsilon^i_{j(i)} = V^i_{xodmk} (X^i_{p, j(i)}) + \epsilon^i_{xodmk}$$

where $j(i)$ stands for the travel sequence $(x, o, d, m, k)$ chosen by the user category $i$

$X^i_{p, j(i)}$ are attributes such as expected travel times, costs, etc., related to the ITS ($P$) scenario

Expected value (mean) of the perceived net utility (surplus) for the chosen alternative (i.e. the one that maximizes its perceived utility) $\rightarrow$ EMPU $= s_p(o, i)$

$$s_p(o, i) = E\left[\max_{xodmk} U^i_p (xodmk)\right]$$

The measure of effectiveness can be:

$$DS_p(o, i) = S_p(o, i) - S_{NP}(o, i)$$
5. impact assessment

Impacts evaluation
Internal effects on transport users

- Behavioral approach

Behavioral models allow to take into account variations in attributes such as travel time reliability, information availability, etc., as much as they are included in the relevant utility functions E.g. Path choice models

\[ V_k = \beta_1 \cdot \text{PTTM} + \beta_2 \cdot \text{PTTSTD} + \beta_3 \cdot \text{STTM} + \beta_4 \cdot \text{STTSTD} \]

\[ + \beta_5 \cdot L + \beta_6 \cdot \text{NSI} + \beta_7 \cdot \text{NLT} + \beta_8 \cdot \text{HDV} \]

where PTTM is the mean travel time (TT) of path k on the primary network, PTTSTS is the standard deviation of TT on the primary network, STTM and STTSTD relate to paths on the secondary network, L is the route length, NSI is the number of signalized intersections along path k, NLT is the number of left turns along path k; HDV is a dummy variable related to highway path choice (taken from Transportation Systems Analysis: models and applications by Cascetta, 2009)

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5. impact assessment

Impacts evaluation
Internal effects on transport users

- Descriptive approach

The demand model can be interpreted as a “demand function” that relates the number of user who make a specific travel choice to the generalized perceived cost of travel

\[ d_{od} = d_{od}(g_{od}) \]
5. impact assessment

Impacts evaluation
Internal effects on transport users

- Descriptive approach

\( g_{\text{NP} \text{ od}} \) is the generalized perceived cost in the no-ITS (NP) scenario

\( d_{\text{od}}(g_{\text{NP} \text{ od}}) \) is the number of user who travel in the no-ITS scenario

If \( g \) reduces to \( g_{\text{P} \text{ od}} \) (due the ITS implementation), the number of user who accept to travel increases to \( d_{\text{od}}(g_{\text{P} \text{ od}}) \)

The Total Surplus variation is the shadowed area

Descriptive:
Average Cost approach

\[
\tilde{g}_{\text{noATIS}} = 0.7 \cdot 15 + 0.3 \cdot 20 = 16.5 \text{ min} \\
\tilde{g}_{\text{ATIS}} = 0.6 \cdot 15 + 0.4 \cdot 20 = 17.0 \text{ min} \\
DS = \frac{1}{2} \left[ f^T \left( \tilde{g}_{\text{noATIS}} \right) + f^T \left( \tilde{g}_{\text{ATIS}} \right) \right] = 1000 \cdot (16.5 - 17) = -500
\]

Behavioral:

\[
V_4 = -\text{meanTT}_4 - 2 \cdot \text{stdTT}_4 \\
V_{\text{noATIS},4} = V_{\text{ATIS},4} = -25 \text{ min} \\
S_{\text{noATIS}} = 1000 \cdot \ln \left[ \exp(-25) + \exp(-30) \right] = -24993 \\
S_{\text{ATIS}} = 1000 \cdot \ln \left[ \exp(-25) + \exp(-24) \right] = -23687
\]

\[ DS = S_{\text{ATIS}} - S_{\text{noATIS}} = 1307 \]
5. impact assessment

**ITS solutions**

*Classification of the impacts (variation between two states)*

- **WELLFARE**
- **SOCIAL AND ECONOMIC COESION**
- **SAFETY**

**SOCIAL SYSTEM**

- **USERS**
- **OTHER TRAVELLERS**
- **SYSTEM OPERATORS**

**INTERNAL IMPACTS**

- **POPULATION LEVELS**
- **RESIDENTS**
- **ACTIVITY LEVELS**

**ECONOMIC AND TERRITORIAL SYSTEMS**

- **POLLUTANT EMISSIONS**
- **NOISE IMPACTS**
- **VISUAL INTRUSION**
- **ENVIRONMENT**

short-term effects

long-term effects

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5. impact assessment

**Impacts evaluation**

*External effects on pollutant emissions*

- **NO ITS SOLUTION**

- **EXISTING POLLUTANT CONCENTRATION**
- **EXISTING TRAVEL PATTERNS AND FREQUENCIES**
- **EXISTING EMISSION RATES OF POLLUTANTS**

**CHANGE IN EMISSIONS**

- **NEW EMISSION RATES OF POLLUTANTS**
- **NEW TRAVEL PATTERNS AND FREQUENCIES**
- **DISPERSION MODELS TO DETERMINE THE ADDITIONAL POLLUTANT CONCENTRATION**

- **ASCERTAIN WHETHER OVERALL POLLUTANT CONCENTRATIONS VIOLATE AIR QUALITY STANDARDS**

- **ITS SOLUTION**

- **SHORT-TERM EFFECTS** (New traffic operations patterns)
  - Higher/Lower speeds, Fewer/more speed change events

- **MEDIUM-TERM EFFECTS** (New demand patterns)
  - Changes in: trip frequency, trip mode, trip route, trip schedule, etc.

- **LONG-TERM EFFECTS** (New land-use patterns)
  - Residential and business re-location

See lecture “Automated Section Speed Enforcement Systems: impacts on traffic, pollutant emissions and road safety” by V. Punzo – Day 2
5. impact assessment

ITS solutions
Classification of the impacts (variation between two states)

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Impacts evaluation
How ITS impacts on road safety

Source: Transportation Decision Making by Sinha and Labi (2007)
5. Impact Assessment

Impacts Evaluation

Effects on Road Safety

Methodologies for the estimation of the change in the number of crashes:

a) Crash Rate Approach

\[ \text{Crashes} = \text{CR} \times \text{VMT} \]

Ex-ante

b) Crash Equation Approach

\[ \text{Crashes} = f(\text{VMT}, X) \]

Ex-post

c) Crash Reduction Factors (CRF)

CR = crash rates by road category
VMT = exposure measure, in terms of traffic volume (AADT) and section length (veic*km)
X = vector of engineering factor values affecting road safety (i.e. those subjected to modification after ITS implementation)

Source: Transportation Decision Making by Sinha and Labi (2007)
5. impact assessment

ITS solutions
Classification of the impacts (variation between two states)

- Welfare
- Social and Economic cohesion
- Safety

Social System

- Perceived by the users
- Not perceived by the users
- System operators

Internal impacts

- Pollutant emissions
- Noise impacts
- Visual intrusion
- Environment

External effects on the activity system

Residents/worker ratios per zone
Total number of jobs in Services
Total number of jobs in Commerce

ODE matrices by mode and purpose

Level of service

Transportation/Land-use interaction models
5. impact assessment

Impacts evaluation
External effects on the activity system

Definition of accessibility:
The ease in meeting one’s needs in locations distributed over space for a subject located in a given area

It depends on the zone where the subject is located, on the spatial distribution of activities on the territory, and on the transportation system that links the origin zone to the others.

Accessibility indicators:

1. Utility-based measures
   a. Non Behavioral approach: Gravity models, LOS models
   b. Behavioral approach: Random utility models

2. Opportunity-based measures
   a. Non Behavioral approach: Isochrones models
   b. Behavioral approach: Perceived Opportunity models
6. comparison of alternatives

Methodologies
Classification

- Cost-Benefit Analysis (CBA)
- Multi-Criteria Decision Making (MCDM)
6. comparison of alternatives

Methodologies
Cost-Benefit Analysis (CBA)

A systematic process for calculating and comparing benefits and costs of a project, decision or government policy.

It involves comparing the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much.

In CBA, benefits and costs are expressed in **money terms**, and are adjusted for the time value of money, so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their net present value.

Source: California DOT [www.dot.ca.gov](http://www.dot.ca.gov)

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**Estimation of the unit cost for monetary benefits/costs**

- Market or economic costs
- Nonmarket costs (shadowed prices) e.g.

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<thead>
<tr>
<th>Costs related to CO, NOx, PM10 emissions (£ct/kvm)</th>
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<th>Costs related to road accident (£2005)</th>
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</tbody>
</table>

Source: National Safety Council (2001)
6. comparison of alternatives

Methodologies

Cost-Benefit Analysis (CBA)

\[ NPV(r) = \sum_{t=1}^{N} \frac{B^t - C^t}{(1 + r)^t} \]

\[ IRR = r : NPV(r) = 0 \]

where \( r \) is the interest rate, \( B^t \) and \( C^t \) are the monetary benefit and costs produced by the project at time \( t \).

Drawbacks:
- Compensation among subjects is virtual, i.e. effects on equity are neglected
- Only quantitative and priced effects are taken into account

6. comparison of alternatives

Methodologies

Multi-Criteria Decision Making (MCDM)

Conflicts between performance criteria rise the issue of Pareto sub-optimality and influences the way in which the different criteria are combined to choose the best alternative. It’s hard to find a solution that yields the highest desired values of all benefit criteria and the lowest ones of all cost criteria.

The objective of MCDM analysis is to help finding the alternative that best achieves a compromise between all competing objectives (i.e. the most satisfying solution) among the set of the non-dominated alternatives (i.e. those lying on the Pareto frontier).
6. comparison of alternatives

Methodologies
Multi-Criteria Decision Making (MCDM)

**STATED OBJECTIVES**
- To improve **Mobility**
- To reduce **Production Costs**
- To reduce **Users’ Generalized Cost**
- To improve **Public Health**
- To reduce **Environmental Impacts**

**PERFORMANCE CRITERIA**
- Variation of Zonal Accessibility
- Variation of Investment and Operative costs
- Surplus variation
- Variation of the crash frequency
- Variation of noise levels
- Variation of \(\text{PM}_{10}\) emissions
- Variation of the \(\text{CO}_2\) eq. emissions
- Variation of visual intrusion in the landscape
6. comparison of alternatives

Methodologies
Multi-Criteria Decision Making (MCDM)

**STATED OBJECTIVES**
- To reduce Inequalities
- To foster Territorial Development
- To foster Economic Growth
- To enlarge Public Consensus upon decisions

**PERFORMANCE CRITERIA**
- Variation of dispersion of transport generalized costs among different zones and/or groups
- Variation of the LOS among target zones
- Variation of housing and commercial densities
- Variation of the internal productivity
- Variation of the Added Value
- Level of acceptance among stakeholders

### Impact Matrix

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>CRITERIA</th>
<th>ALTERNATIVES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>$X_{1,1,1}$</td>
</tr>
<tr>
<td>2</td>
<td>$X_{1,2,1}$</td>
<td>$X_{1,2,2}$</td>
</tr>
<tr>
<td>i</td>
<td>3</td>
<td>$X_{i,3,1}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>N</td>
<td>m</td>
<td>$X_{N,m,1}$</td>
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<td>...</td>
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<td>...</td>
</tr>
<tr>
<td>M</td>
<td>$X_{N,M,1}$</td>
<td>$X_{N,M,2}$</td>
</tr>
</tbody>
</table>

where $X_{i,m,j}$ is the impact level (quantitative or qualitative) of the alternative $j = 1, \ldots, J$ related to the criterion $m = 1, \ldots, M$ associated to the objective $i = 1, \ldots, N$
6. comparison of alternatives

Methodologies
Multi-Criteria Decision Making (MCDM)

Scaling or normalization:
Establishment of a common unit or scale of measurement so that all performance criteria can be expressed in commensurate units to enable comparison or combination of the performance criteria. It involves the establishment of dimensionless unit of desirability (e.g. utility function, value function).

E.g. Value function

\[ x_{i,m,j} = \frac{X_{i,m,j}}{\max_j X_{i,m,j}} \]
\[ x_{i,m,j} = \frac{X_{i,m,j}}{\min_j X_{i,m,j}} \]
\[ x_{i,m,j} = \frac{1}{J} \sqrt{\sum_{j=1}^{J} X_{i,m,j}} \]
\[ x_{i,m,j} = \frac{X_{i,m,j} - \min_j X_{i,m,j}}{\max_j X_{i,m,j} - \min_j X_{i,m,j}} \]

Methodologies
Multi-Criteria Decision Making (MCDM)

Weighting:
Assignment of relative weights to each performance criterion to reflect its importance compared to other criteria

- Equal Weighting
- Direct Weighting
- Regression-based Observer-derived Weighting
- Delphi Technique
- Pair-wise Comparison of performance criteria
  - Saaty Hierarchy Comparison
  - Analytical Hierarchy Process
6. comparison of alternatives

Methodologies
Multi-Criteria Decision Making (MCDM)

Weighting:
- *Pair-wise Comparison of performance criteria*

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>1</th>
<th>2</th>
<th>m</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A_{1,2}</td>
<td>A_{1,m}</td>
<td>A_{1,M}</td>
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</tr>
<tr>
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<td>1/A_{1,M}</td>
<td>1/A_{2,M}</td>
<td>1/A_{m,M}</td>
<td>1</td>
</tr>
</tbody>
</table>

Priorities:
- \[ p_i = \sum_{m=1}^{M} A_{i,m} \]
- \[ w_i = \frac{p_i}{P} \]
- \[ w_m = \frac{p_m}{P} \]
- \[ P = \sum_{m=1}^{M} p_m \]

Elimination criteria:
- Dominance analysis
- Conjunctive method
- Disjunctive method
- Mathematical Programming

Ranking criteria:
- MaxMin and MaxMax
- Combined mathematical functions of Value, Utility, or Cost-Effectiveness (Weighted Sum, Weighted Product, Impact Index)
- Topsis, ELECTRE, AHP

A_{i,j} ranging in a user defined ranking scale, e.g.
- \( A_{i,j} \in [1-5] \) if criteria \( i \) dominates \( j \)
- \( A_{i,j} \in [1/5-1] \) if criteria \( j \) dominates \( i \)
6. comparison of alternatives

Methodologies
Multi-Criteria Decision Making (MCDM)

Combination and Decision:

- **Impact Index Method**

\[ I^k_j = \sum_{m=1}^{M} \left( w_m \cdot x_{m,j} + e_m^k \cdot w_m \cdot x_{m,j} \right) \]

\[ I_j = \frac{1}{K} \sum_{k=1}^{K} I^k_j \]

where \( x_{j,m} \) is the normalized impact level of the alternative \( j \) related to the criterion \( m \), \( w_m \) is the weight of the criterion \( m \), and \( e_m^k \) is the \( k \)-th sample of a random number drawn from a-priori probability distribution (if not known, a uniform rectangular distribution ranging from -0.5 to 0.5 is considered).

---

6. comparison of alternatives

Methodologies
Evolution of the Multi-Criteria Decision Making

Multiple Agent Multi Criteria Decision Making (MAMCDM)

**Stakeholder 1**

- Identify competing alternatives
- Define objectives
- Establish performance criteria for each objective
- Establish relative importance of performance criteria

**Stakeholder 2**

- Identify competing alternatives
- Define objectives
- Establish performance criteria for each objective
- Establish relative importance of performance criteria

**Stakeholder k**

- Identify competing alternatives
- Define objectives
- Establish performance criteria for each objective
- Establish relative importance of performance criteria

... **Stakeholder n**

- Identify competing alternatives
- Define objectives
- Establish performance criteria for each objective
- Establish relative importance of performance criteria

Rank of alternatives

- Determine the most shared alternative

Rank of alternatives

Rank of alternatives
6. comparison of alternatives

Methodologies
Evolution of the Multi-Criteria Decision Making

Multiple Agent Multi Criteria Decision Making (MAMCDM)

It allows to take into account multiple stakeholders in the assessment, through a multiple weighting scheme and similar elimination/ranking criteria for “shared” decision making:

- Raking based on consensus
- Ranking based on votes or compromise
- Ranking based on a geometric mean of stakeholders preferences
- Ranking based on separate aggregation models (e.g. exchange rate model)

LEVEL OF ACCEPTANCE

6. comparison of alternatives

Methodologies
Uncertainty in the evaluation and comparison of ITS solutions

Input Variables and their probability distributions

Probabilistic Multiple Criteria Evaluation

Using any relevant of the methods available

Outputs and their probability distributions or confidence intervals

Joint probability distribution of combined output (Index) representing multiple performances

Variability of final evaluation results and decision

Discrete probability distribution for evaluation outcome (i.e. probability that the alternative turns out to be the most satisfying)

Examples: Agency costs, user costs, demand, interest rate, etc.
basic references

Modeling Transportation Systems

Impact Assessment

Comparison of Alternatives