knowledge representation of infrastructure shortfalls: models for expert & citizen input

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I - Determination of minimum infrastructure requirements for different land uses

(11.981 Graduate Tutorial on Land Development and Infrastructure, Fall 92)

II - Knowledge about primary and secondary consequences of infra-structure shortfalls : library of default representation formats

(MIT PhD Thesis Chapter (2002)

III - Question-Answer on Infrastructure shortfalls

(MIT PhD General Examinations, 1993)

I

Determination of minimum infrastructure requirements for different land uses

11.981 Graduate Tutorial on Land Development and Infrastructure-----------Fall 92

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Goal:

To provide planners with a tool (or set of tools) to help in strategic decision making regarding
- infrastructure sectoral priorities
- site priorities

for infrastructure investment/development efforts.

Immediate goal:

To evaluate the feasibility and potential of this approach to research the effects of infrastructure shortfalls, by documenting a small subset of cases;

Description:
(of proposed tool and respective process of use, that is, steps inserted in the decision-making process)

Tool:

- Table (or tables) of minimum required infrastructure standards/levels of reliability *per* type of land use (ex: agriculture-rice; industry-glass; etc.), *per* class of context (ex: environment-stressed; location- metropolitan; etc.). Possible formats to represent this table:

a) Simple text table;

b) Expert System with a collection of cause-effect rules to derive the best possible guess for the minimum requirements;

c) Model with weighted coefficients, to derive several indexes of service levels.

Process:

- a) Collect detailed information on land use in concerned areas;
- b) Identify type/class of context in concerned areas;
- c) Compare current situation of infrastructure in the concerned areas with the Table of minimum requirements; establish a measure of the existent gap, or distance, between current situation and critical requirements;
- d) Use the measured gap to identify which infrastructure sectors, and which sites, should be given priority;
- e) Readjust found priorities to account for other factors, such as different macro-economic impact of sectors and sites, etc.

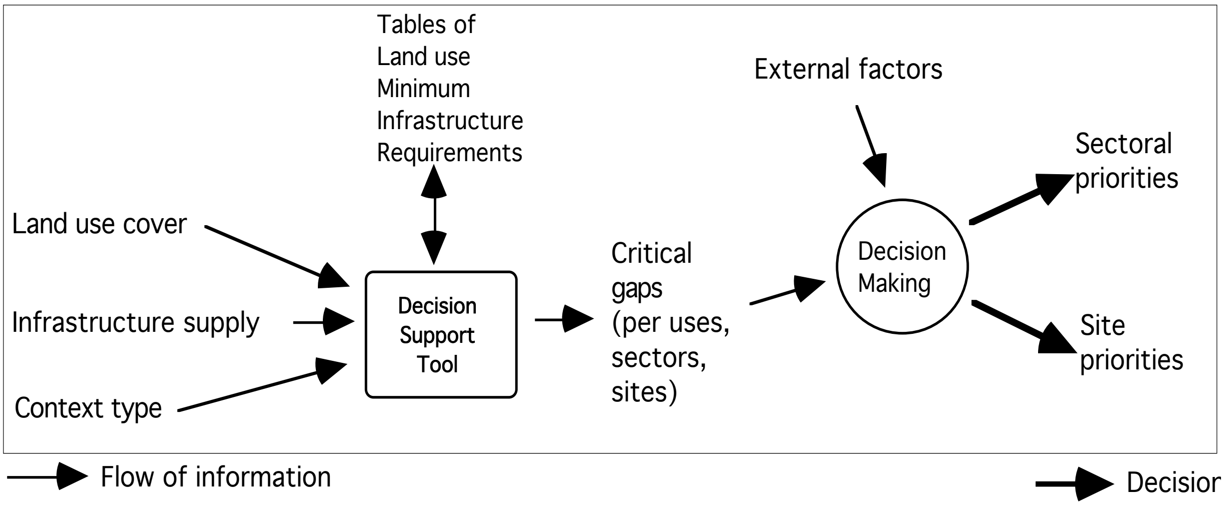

Fig. 1 Use of tool in strategic decision making on infrastructure development

<u>Assumptions</u>:

Like any model, the proposed decision-support tool operates under certain assumptions, defining the limits of its application scope:

1) [Specialization assumption]: Different land uses in different contexts are affected unequally by infrastructure shortfalls;

2) [Generalization assumption]: The same land use in the same context have similar minimum requirements of infrastructure standards and levels of reliability;

3) [Aggregation assumption]: It is possible to identify a small number of typical contexts for a large variety of land uses, in different places;

4) [Relevance assumption]: External factors (that is, factors not related with functional infrastructure requirements derived from land use, nor related with pre-defined typical

contexts), such as macro-economic considerations, are not the main determinant of the impact of infrastructure development - or, at least, not always;

5) [Monotonic assumption]: Current land uses and respective contexts will not change significantly if the current levels of infrastructure service are maintained; that is, the growth rate is uniform - the same for all land uses;

6) [Conservative assumption]: Current land uses and respective contexts will not change significantly as a result of posterior infrastructure development, if this infrastructure development is targeted specifically to serve the current land uses - and not to change them.

NOTE: relaxing assumptions 5 or 6 will imply to use iterative models, or system dynamics.

Methodology:

(for the overall goal)

• 1) Build a table for each identified land use with the minimum infrastructure requirements (standard, reliability) associated with that use;

Example of such table (very general):

Land Use	Context	Water	Sewer	Power	Transportation	Telecommunications
Export of perishables		Medium standards Medium Reliability	High standards High reliability	Medium standards High reliability	High standards High reliability	Medium standards Medium Reliability
High-Tech Computer Industry		Low standards low reliability	Low standards low reliability	Medium standards High reliability	High standards High reliability	High standards High reliability

Residential	Location-Metropolitan-Large Population-Density-High Population-Income-High	High standards high reliability	High standards High reliability	Medium standards High reliability	Medium standards High reliability	High standards High reliability
	Location-Rural-Homogeneous Population-Density-Low	Medium standards Medium reliability	Medium standards Low reliability	Low standards Low reliability	Medium standards Low reliability	Low standards Low reliability
Fruit trees		Medium standards high reliability	Low standards low reliability	None	Medium standards High reliability	None

Table 1: From Land Use to Minimum infrastructure requirements (standard, reliability)

While it is possible to build portions of this table by deduction or by normative definition of infrastructure requirements for certain operations (like irrigation of tomato, etc.), it is probably easier to start from the other end, that is, by collecting evidence of what are the effects of infrastructure shortfalls, including unreliability, for each type of land use; and then infer from these effects what are the minimum, critical requirements. Therefore, we need to:

• 2) Build tables with the effects of shortfalls of each infrastructure service in each type of land use;

Examples:

Land Use	Context	Power (level of service)	Consequences Disruption of Use	Externalities
Industry handling frozen materials		frequent interruptions (measure of frequent?)	serious (market - exit)	
High-Tech Computer Industry		frequent interruptions (measure of frequent?)	serious (market - exit)	

...
...

Land Use	Context	Communications (level of service)	Consequences Disruption of Use	Externalities
Manufacturing	Location-Metropolitan-Large	reliability: poor	serious (market-exit)	low (impact of market exit)
with just-in-time inventory	Location-Rural-Heterogeneous	reliability: poor	serious (market-exit)	high (impact of market exit)
Brokerage firm		reliability: poor (less than 70% completed calls)	serious (market-exit)	

...

Table 2 A-E: Effects of shortfalls *per* Infrastructure *per* Land Use

While some consequences of shortfalls will be context-independent, that is, depending only on the nature of the land use, in many cases the consequences will be context-dependent. Perhaps the most difficult task will be to identify a small number of classes of contexts, in a meaningful way. Therefore, we need to:

• 3) Define classes of contexts;

Examples:

Context		Qualifiers	Description
Environment	Water-Table	Good,Normal,Bad	
	Air-Quality	Good,Normal,Bad	
Location	Metropolitan	Large,Medium,Small	
	Rural	Homogeneous, Heterogeneous	
Population	Density	High,Medium,Low	
	Income	Homogeneous, Heterogeneous	
	Growth-Rate	High,Medium,Low	
Institutional	Capacity	High,Medium,Low	
	Efficiency	High,Medium,Low	
	User-feedback	High,Medium,Low	

Table 3: Classes of Contexts

• 4) Identify the best representation format (Text table, Expert System, Model of weighted coefficients);

If the minimum infrastructure requirements (MIR) can be directly defined for each land use, full information is available, and context dependencies are simple (one step inferences), then a *Text Table* is probably the adequate format;

If the MIR can only be derived from intricate cause-effect relationships, or full information is not available, or context dependencies are complex, then a *Expert System* is probably the best format;

If cause-effect relationships defining the MIR can be easily expressed as mathematical relationships, and the levels of service can be expressed by numeric indexes, then a *Weighted Coefficients Model* is probably the most useful format.

• 5) Test on the field the use of the table(s), in the adopted format, in the strategic decision-making process.

Short term project:

Build samples of tables described in 1) to 3), in simple text format, for a few cases; provide small example of other formats (Expert system, Model).

Pending issues:
(need to elaborate later)

Link to Pete Cook's "level indicators" and Arturo Israel's "Voice", role of feedback;

Visualization and spatial analysis, using GIS hooked to this system;

Fine tuning by desegregating tables defining levels of service, measures of reliability, definition of context, discrimination of land uses; how to move along the aggregation-desegregation dimension.

The issue of costs, linked also to individual (private) substitutes.

References:

"Expert System for the effects of infrastructure shortfalls", Pedro Ferraz de Abreu, research notes, 1991.

"Issues for Infrastructure management in the 1990s", Arturo Israel, World Bank discussion papers, 1992.

"Improving infrastructure planning and management accountability: The service level indicator approach", Pete Cook, Jonathan Stevens, 1992.

II - Knowledge about primary and secondary consequences of infra-structure shortfalls : library of default representation formats

(MIT PhD Thesis Chapter (2002)

My own approach, applied to my area of concern (EIA), was to consider building a library of default representation formats for each kind of "knowledge unit", in the domain of impact assessment considered by the system.

For instance, knowledge about primary and secondary consequences of infra-structure shortfalls and of each alternative action, is more about causal relationships (if truck traffic and weak pavement than new road is needed) than about knowledge in depth about entities or objects (roads, trucks); this points towards a rule-based representation and reasoning. Other knowledge domains may depend on much weaker cause-effect relationships and be instead more based on precedent experience (like border cases in environmental law applications), pointing towards a case-based representation and reasoning. Yet other domains may be based on in-depth knowledge about entities, or objects (like land uses, or parametric description of water treatment systems), hence pointing towards the use of object-oriented or frame-based representation and reasoning (Booch 1991).

To build a library of links between domain and representation, one needs to associate with each knowledge unit a descriptor about itself, or "metaknowledge" descriptor (Davis 1977). For the sake of tradition, I will use in this thesis the term metadata with the wider definition that include the metaknowledge concept.

Although my earlier work in this area targeted other application areas (such as infrastructure shortfalls and natural resource management), I can draw upon this experience for this thesis research, as I discuss next.

3.3.5.2. - Rule-based representation (expert system for infrastructure shortfalls)

Rule-based representation is usually associated with knowledge expressed in cause-consequence relationships, or "causal reasoning". Expert systems are the most typical approach to handle rule-based representation and use it to infer reasoning chains. There are many examples of successful expert systems in areas like finance and diagnosis. MYCIN (medical diagnosis), developed at MIT, is one of them (Kurzveil 1990).

Applying this representation paradigm to deal with planning knowledge, I developed a prototype of an expert system dedicated to explore the cycles of cause-consequence in relation to infrastructure shortfalls (Ferraz de Abreu 1991b).

This system in particular uses a forward chaining inference engine, that I developed and programmed based on my previous work on intelligent graphic interfaces (Ferraz de Abreu 1989a), and 5 classes of rules: definition, qualitative, quantitative, spatial, and question. Fig. 3.3.5.2. - 1 shows an index of the rules and classes in this expert system.

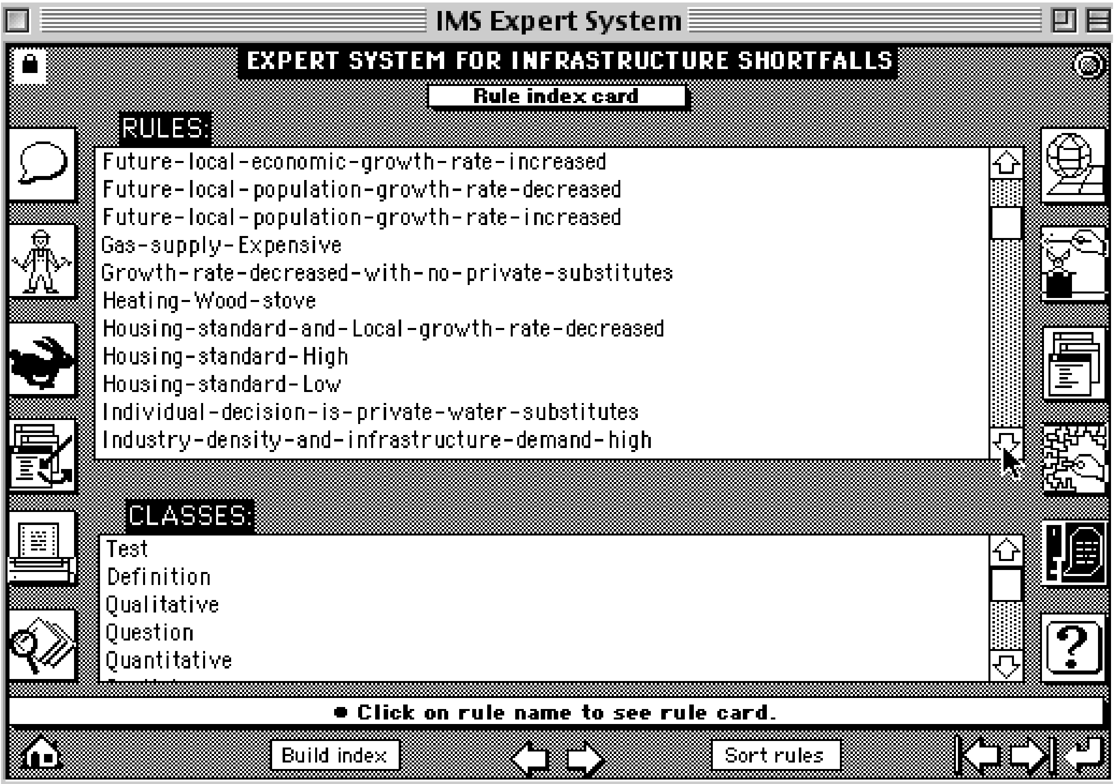

Fig. 3.3.5.2. - 1 - Rule Index card in the Expert System for Infrastructure Shortfalls

It is useful to consider a brief example of the correspondence between the issue (or reasoning) and its rule representation:

Suppose we have a great number of low-income households, therefore with very low housing standards, and that there is no service providing gas or other cooking / heating fuel (a shortfall).

These houses are likely to have poorly ventilated wood stoves. This will cause indoor pollution (a primary consequence). Then, this will cause high rates of children suffering from chronic lung disorders; then, this will cause their mothers to lose hours of work time caring for them (secondary consequences); then, this will bring low productivity; if an epidemic arises, increased public health costs (aggregated secondary consequences).

Representing this reasoning with rules is fairly straightforward:

IF household IS low-income
THEN house-infrastructure IS low-standard
ventilation IS poor

IF house-infrastructure IS low-standard AND
heating-fuel IS-NOT available
THEN house-heating IS wood-stove

IF house-heating IS wood-stove AND
ventilation IS poor
THEN indoor-pollution IS high

IF indoor-pollution IS high
THEN rate-of-children-lung-disorder IS high

IF rate-of-children-lung-disorder IS high
THEN mothers-productivity IS low
public-health-costs IS high

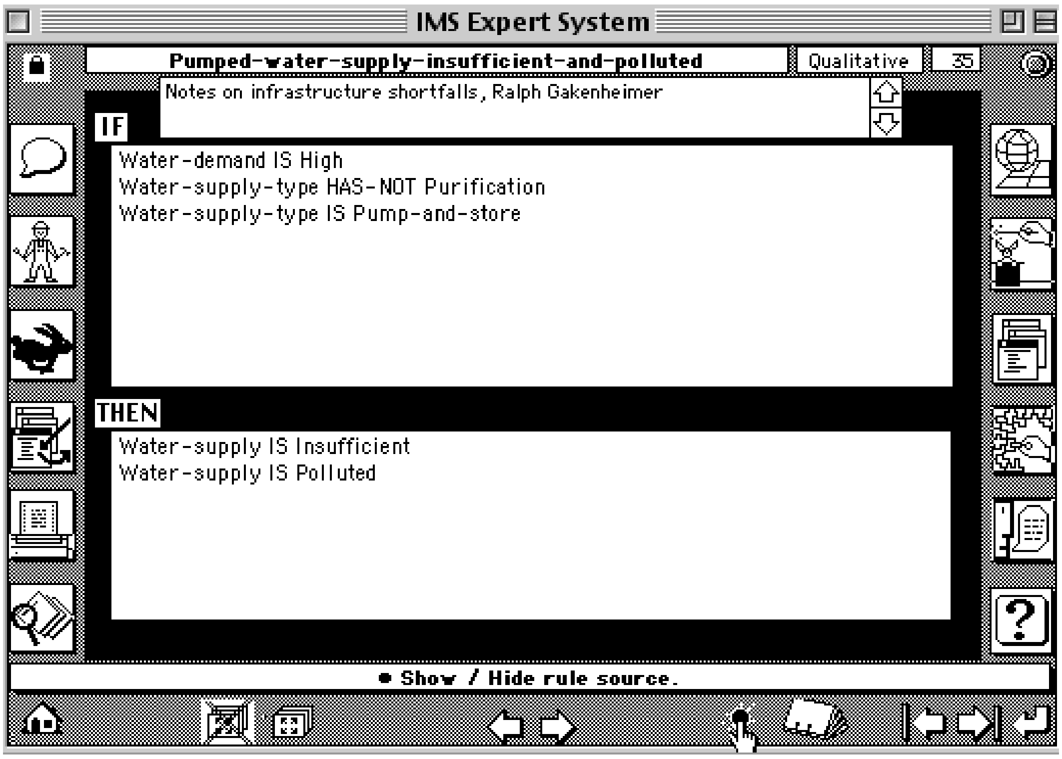

Fig. 3.3.5.2. - 2 - Rule example in the Expert System for Infrastructure Shortfalls

Fig. 3.3.5.2. - 2 shows how one of these rules is represented in the system.

The rule representation of the above reasoning is therefore adequate and simple. However, if we consider now that low productivity and increased costs are likely to cut on salaries and on health subsidies, which will perpetuate the low-income of the original families considered, we have a positive feedback or reinforcement of secondary consequences over the primary consequences. Representing these facets of causal reasoning with a rule-based system is not so trivial.

Because of the cyclical nature of the inference net, that is, a graph with cycles instead of a tree-graph, I implemented the inference engine in such a way that the user can visualize (Fig. 3.3.5.2 - 3) the intermediate steps of the inference process, and not just the final inference set (as it is more common). The output of this system can be extended to suggest policy recommendations, or estimate costs of shortfall situations. However, rule-based representation is clearly more suited to knowledge that can be expressed in tree-like inference nets.

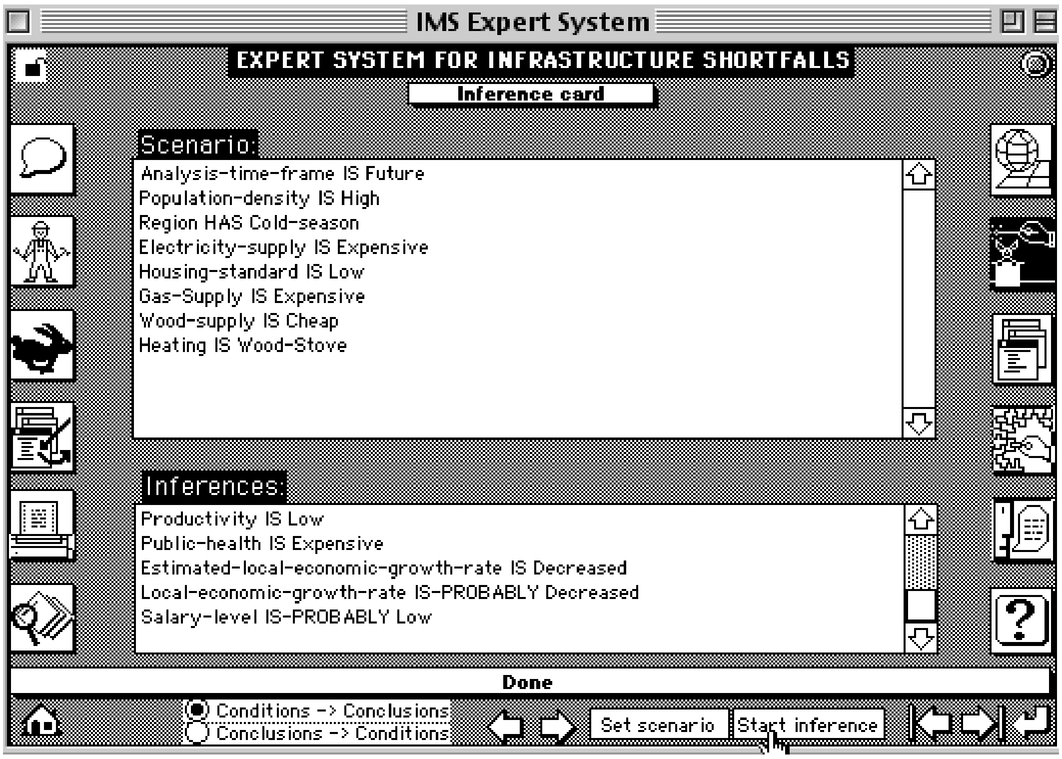

Fig. 3.3.5.2. - 3 - Expert system inference showing intermediate steps

3.3.5.3. - Rule-based vs. regular grammar representation and reasoning

Environmental impact assessments is a domain that, at first sight, seems to suit itself well to a rule-based representation model, since it is frequent to listen to experts arguing for cause-consequence relationships, using a "causal reasoning". But instead of the usual tree of inference, many problems in impact assessment demand also other forms (like a non-tree graph, or graph with loops) able to capture cycles and feedback. Representing cycles is important because consequences of impacts, just like the infrastructure shortfall example, may affect individuals, activities and the environment in general, cycling through all of them. A cycle implies that some kind of feedback is present, either positive (reinforcement) or negative (regulation). In such cases, a "regular-grammar" (state automata) representation model may be more adequate. To clarify my application of the notion of positive and negative feedback's in modeling shortfall consequences, consider this more aggregated graph of inferences with the following factors:

In a city, there is a poor garbage collection service, resulting in the accumulation of garbage in the area (G). This will increase the number of bacteria present in the area (B). This will increase the number of diseases (D). All these are direct proportionality functions (if the number of G increases, B increases; if G decreases, B will decrease). Now consider that increasing diseases will induce people to leave the city (or will kill people), causing the reduction of the number of people in the city (P). This will cause the quantity of garbage to decrease, that is, a case of negative feedback or regulatory effect of the secondary consequences over the primary consequences.

In Fig. 3.3.5.3.-1 is a graph representation of this simplified model (adapted from (Maruyama 1973)), with other dimensions added: S for sanitary improvements (which will decrease directly both the number of diseases and bacteria); C for migration into the city (increasing the number of people in the city) and M for modernization of the city. In general, a + sign identifies a direct proportionality relationship, a - sign the inverse proportionality.

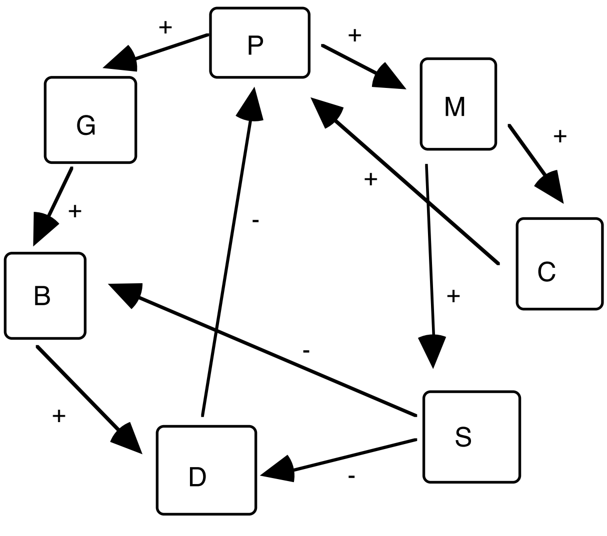

Fig. 3.3.5.3.-1 - Graph representation of the inference net of shortfall consequences

This representation formalism is simple, yet very powerful. For instance, by counting the number of negative signs (inverse proportionality relationships) within a complete cycle, it is possible to forecast either a positive feedback - reinforcement (even number of minus signs) or a negative feedback - regulation (odd number of minus signs), for that cycle.

Several authors developed models of different aspects of these relationships that have some component relevant to the analysis of the shortfall implications. Laredo emphasizes the importance of the sector linkages of water services in its impact on agriculture, industry, health, and housing (Laredo 1990). Scenarios involving infrastructure shortfalls kind of problems can serve as a testbed for the potential of this representation formalism.

III - Question-Answer on Infrastructure shortfalls

(MIT PhD General Examinations, 1993)

Question:

In a metropolitan region in a developing country, there is an area (a few hundred square miles) with the following basic public infrastructure services:

- full sewage system;
- intermittent water service (irregular interruption every 8 hours, in average);
- intermittent power supply (irregular interruption every other day, in average);
- 8 meter wide access road, macadam.

a) Is this a situation where there is an infrastructure shortfall? Justify.

b) Suppose the current dominant land use is residential, and you are in charge of a study to propose infrastructure improvements in that area, with a limited budget. What priorities will you define? Justify your proposal in terms of cost/benefit analysis describing a plausible scenario, and indicate the study methodology used to reach those conclusions.

c) The same, now supposing the dominant land use is industrial.

d) Due to a national financial crisis, there is a serious risk that even your limited budget will not be available for the next 5 years. What are your projections for the evolution of land uses in that area in five years, considering the scenario adopted in b) (dominant residential) and in c) (dominant industrial)? Justify describing your forecast model, including a plausible estimation of population growth.

e) With the experience acquired while serving that area, you are now contracted to produce a prototype of an expert system to help city managers to evaluate the consequences of infrastructure shortfalls, and ask what-if questions in function of different strategies of prioritizing infrastructure development. Outline a model for such an expert system, including: the knowledge representation formalism adopted, the inference engine algorithm, and the boundaries of application of the model.

Question II-2:

The dynamics resulting from infrastructure shortfall are among the most challenging issues within both the domains of infrastructure and urban transition. The general effects of infrastructure development are widely studied, but its reverse coin, the impact of shortfalls, is more elusive.

1. The concept and measure of infrastructure shortfall:

One of the reasons is that it is much harder to generalize definitions of infrastructure shortfalls. Is a public power supply, available at proper voltage for 95% of the time and a breakdown average of twice a year, a condition of shortfall? Residents from Roxbury, Massachusetts, will feel sometimes annoyed, but most of the time they will not even notice it. People from the small village of Nador, Tunisia, presently only served a few hours a day, will consider it as a blessing from heaven. But for a modern milk processing plant, it could as well be 5 % of the time: they will have to invest in installing their own generators with 100 % capacity, because any voltage surges and drops at a critical time may produce such damage that they cannot afford the risk. For the milk plant, there is no doubt a public power supply shortfall.

It would be reasonable then to assume that the notion of shortfall depends on the consumer need, and therefore one must know the consumer activity to identify a shortfall. But consider this situation: some place, unknown location and characteristics, has only "soak-away" sanitary installations. We don't need to know anything else to declare a condition of shortfall, because it arises from the sole nature of the service and the "absolute" level of service provided. It follows that, in order to study the dynamics of infrastructure shortfalls, we need to consider both absolute and relative (context-dependent) criteria, and build both a deduction-based and an empirically, induction-based inference net of cause-effect relationships.

A further complexity is introduced by the fact that, although it would be simpler to consider each infrastructure sector dynamic independently, most of the relationships involve intersectoral interaction. Other infrastructure characteristics that are relevant to the nature of shortfall consequences, are its construction-intensive and technological-intensive traits, as well as its system / network nature, with corresponding idiosyncrasies in demand, threshold phenomena, propagation of failure effects, etc.

Shortfalls can assume multiple faces: no public service (or legally authorized service); existing service but insufficient supply; or poor quality; or poor reliability [Gakenheimer 90]. If there is no public service, there may or not exist an appropriate individual (or private) substitute. The shortfall may be a consequence of lack of a combination of services, and usually has multi-sectoral consequences. Land use, institutional, environmental, economical, political, social, and public health impacts are frequently felt, although some might not be immediately visible. Evaluating the costs of shortfalls would be useful, but given that many primary and secondary consequences are externalities, there is no simple scale. Some indicators have been suggested, like the costs of recuperating a degraded urban area, and/or environment; and the costs of upgrading standards.

The elusive nature of the shortfall problematic is maybe a mirror of another well known debate, regarding the issue of "basic needs" of infrastructure. The basic needs concept would be an elegant and simple way to identify and measure a shortfall (or an overcapacity): the gap between service provided and the respective basic need.

To begin with, most states and localities typically limit their infrastructure analysis needs to "basic" services - highways and bridges, water and sewer [Kaplan 88]. We must consider also services like roads and walk ways, drainage, human waste disposal, solid waste disposal, electricity, telecommunications, fire protection, etc. Stein, Kaplan and others point to the fact that researchers are not always able to distinguish between "backlog", "recurring", and "growth-oriented" needs [Stein 88].

Next, existing standards generally assume that infrastructure costs and prices will remain stable. In fact, infrastructure needs are likely to change dramatically if costs change or governments eliminate subsidies [Kaplan 88]; in consequence, users of infrastructure will change their demand, in function of how much alternative services (or other goods) they will have to give up. Infrastructure serves fundamental needs, but often replaces individual substitutes.

Finally, different patterns of infrastructure "consumption" is another variable disturbing the notion of "basic need". Anne White showed how low-income domestic water use varies significantly not only in function of rural vs. urban, as it would be expected, but also from country to country and continent to continent, suggesting some degree of culture dependency [White 74]. Also Schlomo Angel reports a survey concerning the felt priorities by low-income communities regarding "basic needs" in infrastructure, and they vary from water supply, to garbage collection, to electricity, to playgrounds, sometimes within the same location, but in different types of settlements [Angel 81]. It is not clear what can be extracted from these results, other than it is hard to pin down a definition of a "basic need".

2. Consequences of shortfalls:

Let us consider a city partly served by network infrastructure, and served partly inadequately by those networks on account of their condition. By listing examples of shortfalls, we can follow their primary and secondary consequences; the sequence of examples will put together a collective picture of a fictional city, sharing many of the traits of several real ones.

These consequences may affect individuals, activities and the environment in general; in fact, they frequently cycle through all of them.

2.1 Consequences starting at individual level:

Suppose we have a great number of low-income households with very low housing standards, and that there is no service providing gas or other cooking / heating fuel (a shortfall). These houses are likely to have poorly ventilated wood stoves. This will cause indoor pollution (a primary consequence). Then, this will cause high rates of children suffering from chronic lung disorders; then, this will cause their mothers to lose hours of work time caring for them (secondary consequences); then, this will bring low productivity; if an epidemic arises, increased public health costs (aggregated secondary consequences); low productivity and increased costs are likely to cut on salaries and on health subsidies, which will perpetuate the low-income of the original families considered (positive feedback or reinforcement of secondary consequences over the primary consequences).

2.2. Consequences starting at city level:

Other examples with negative feedback are possible too. To clarify my application of the notion of positive and negative feedback's in modeling shortfall consequences, consider this more aggregated graph of inferences with other factors:

In our city, there is a poor garbage collection service, resulting in the accumulation of garbage in the area (G). This will increase the number of bacteria present in the area (B). This will increase the number of diseases (D). All these are direct proportionality functions (if the number of G increases, B increases; if G decreases, B will decrease). Now consider that increasing diseases will induce people to leave the city (or will kill people), causing the reduction of the number of people in the city (P). This will cause the quantity of garbage to decrease, that is, a case of negative feedback or regulatory effect of the secondary consequences over the primary consequences.

In Fig. 1 is a graph representation of this simplified model, with other dimensions added: S for sanitary improvements (which will decrease directly both the number of diseases and bacteria); C for migration into the city (increasing the number of people in the city) and M for modernization of the city. In general, a + sign identifies a direct proportionality relationship, a - sign the inverse proportionality.

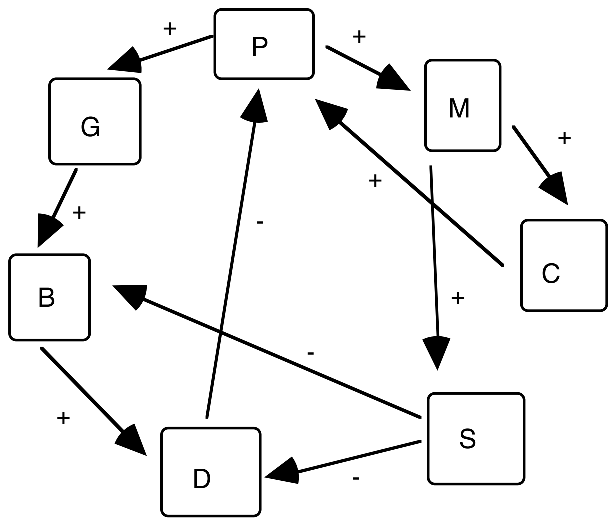

Fig. 1 graph representation of the inference net of shortfall consequences

Several authors developed models of different aspects of these relationships that have some component relevant to the analysis of the shortfall implications. Laredo emphasizes the importance of the sectoral linkages of water services in its impact on agriculture, industry, health, and housing [Laredo 90].

2.3. Consequences in environment:

As a natural resource, water is one of the elements that play a larger role in the web of cause-effect relationships involving infrastructure shortfalls. Suppose that our city, located in a coastal area, with a high population growth rate, has still an old water system, with a ground water basin that uses artificial recharge. Given the population growth, it is likely that there is a persistent overdraft, that is, the amount of water being removed from the basin exceeds the amount of water being restored (or the safe yeld is exceeded). This will cause pumping water from a deeper water table. This will have two consequences: increasing costs (deeper pumping is more expensive) and the water table level falls. This will have as a consequence sea water to intrude into the freshwater in the aquifer, first affecting the quality of the water, then rending it undrinkable. At the same time, use of wastewater as an artificial recharge contaminated the basin. Besides, if the pressure on water pipes decreased, ground water penetrated the network, maybe contaminated by some leaks on the sewer system. The final consequences are either a monumental cost to rehabilitate the water table, or the degradation of the living conditions in the city to an intolerable level for many people, which will decide to leave.

2.4. Consequences for industry:

Let us suppose that in our troubled city, besides the poor water supply in crisis, the power supply was subject to frequent cuts and power fluctuations. This will have as a consequence that local industry will have to invest in generators and maybe water treatment plants, to avoid production losses and equipment damages. The primary consequence will be raising production costs and "*lengthen the gestation period of industrial projects*" [Lee 89]. This is particularly serious for small firms, which don't have the capacity to invest in private substitutes. Small firms usually have an important role in the overall growth and job offer. Therefore, growth will slow down, as well as employment generation, and small firms will tend to dislocate to an area better served by infrastructure (secondary consequences).

Alex Anas and Kyu Lee consider that manufacturers have typically four alternatives: To relocate (within the city, or from one region to another); To change product (factor substitution) or production processes that are less infrastructure demanding ; private provision (of the infrastructure services in shortfall); or output reduction (or shutdown) [Lee 89]. It is also referred to arrangements where some manufacturers, individually or in group, may sell extra capacity of their private substitutes to "satellite" firms, provided that the legal framework does not block such arrangements. Each one of these alternative decision-paths will lead to different scenarios with yet other (distinct) consequences.

3. Role for information systems:

Given the complexities of this problem, information systems play an important role as aids for gathering and structuring related information, for analysis, and for experimenting research hypothesis through simulation. Decision Support Systems may help national agencies and local governments to make strategic choices, such as: between different users of the infrastructural services (e.g. residential vs. commercial vs. manufacturing); between capital investments and maintenance of existing services; between different infrastructure sectors; between different city and regional priorities; and between different institutional and regulatory arrangements.

Different kinds of information systems play different roles. Ortolano refers to several model-based systems to study the impact of infrastructure on land use: conventional multiple regression models, dynamic simulations, multiple-market equilibrium models [Ortolano 88]. Krueckeberg suggests that different land uses or activities have typical data found repeatedly associated with them in information systems:

Residential (population, density, car ownership, income, family size, number of dweling units)
Manufacturing (number of employees, acres, shipments)
Transportation (employees, acres, parking capacity, berths)
Communications and Utilities (idem)
Services - medical, educational, etc - (acres, attendance, capacity, employees)
Cultural, entertainment and recreational (acres, attendance, capacity)
Agriculture (Acres, employees, shipments)
Mining (idem) [Krueckeberg 74]

Sharpe describes several prototypes of expert systems, such as the one developed to advise operators of the Melbourne water and sewerage networks, using data provided by the Integrated Telemetry Network. The ITN continuously checks for pump faults, pressure limit violations, flow rates, valve positions, water levels, and report abnormal conditions on computer consoles to system operators for action [Sharpe 91]. I developed a prototype of an expert system dedicated to explore the cycles of cause-consequence relationships in relation to infrastructure shortfalls. This system uses a forward chaining inference engine, and 5 classes of rules: definition, qualitative, quantitative, spatial, and question (examples of these rules are in appendix). Because of the cyclical nature of the inference net, that is, a graph with cycles instead of a tree-graph, I implemented the inference engine in such a way that the user can visualize the intermediate steps of the inference process, and not just the final inference set. The output of this system can be extended to suggest policy recommendations, or estimate costs of shortfall situations.

In Fig. 2, I introduce a diagram modeling the role of information systems in the quest for analyzing and correcting infrastructure shortfall problems. The diagram proposes four levels at which information systems may operate, and complement each other: source level, conceptual level, analytival level, and use level.

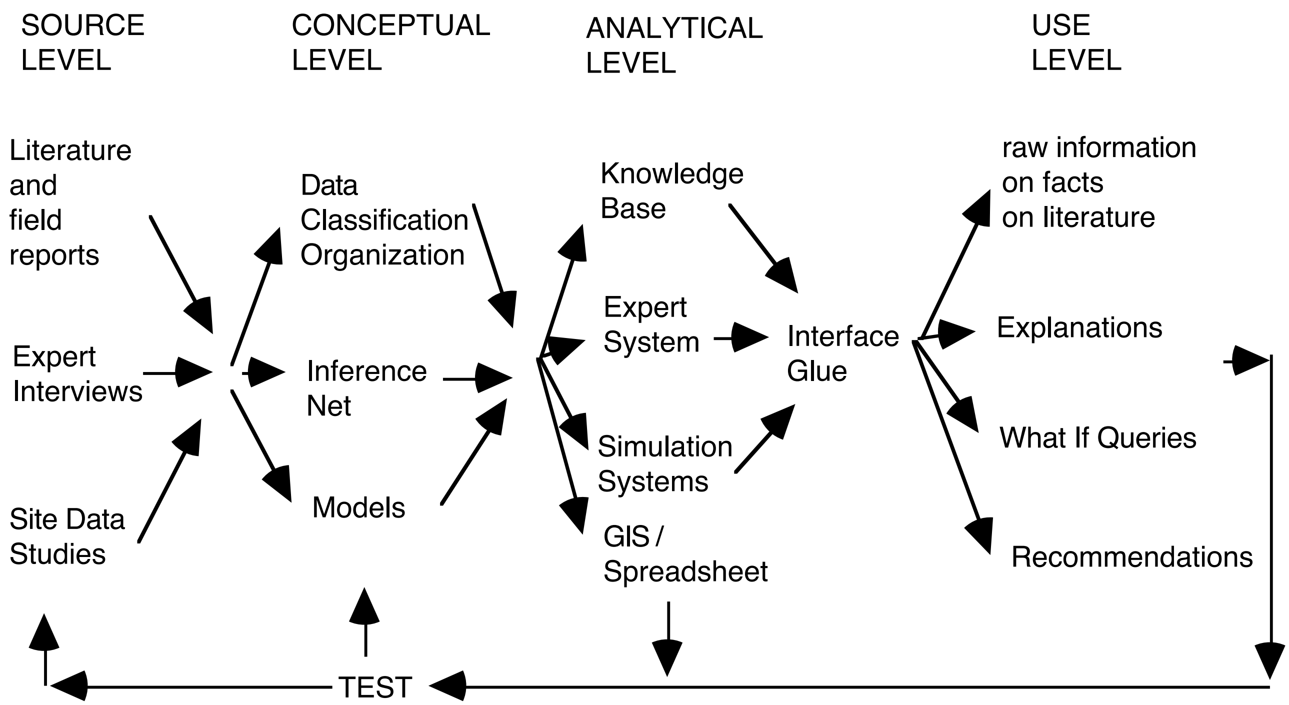

Fig.2 Role levels for information systems on infrastructure shortfalls

In Fig 3, I introduce a diagram representing the role of a specific tool to help in strategic decision making regarding infrastructure sectoral development priorities and site investment priorities. The process described in the diagram is the following:

- a) Collect detailed information on land use in concerned areas;
- b) Identify type/class of context in concerned areas;
- c) Compare current situation of infrastructure in the concerned areas with the Table of minimum requirements; establish a measure of the existent gap, or distance, between current situation and critical requirements;
- d) Use the measured gap to identify which infrastructure sectors, and which sites, should be given priority;
- e) Readjust found priorities to account for other factors, such as different macro-economic impact of sectors and sites, etc.

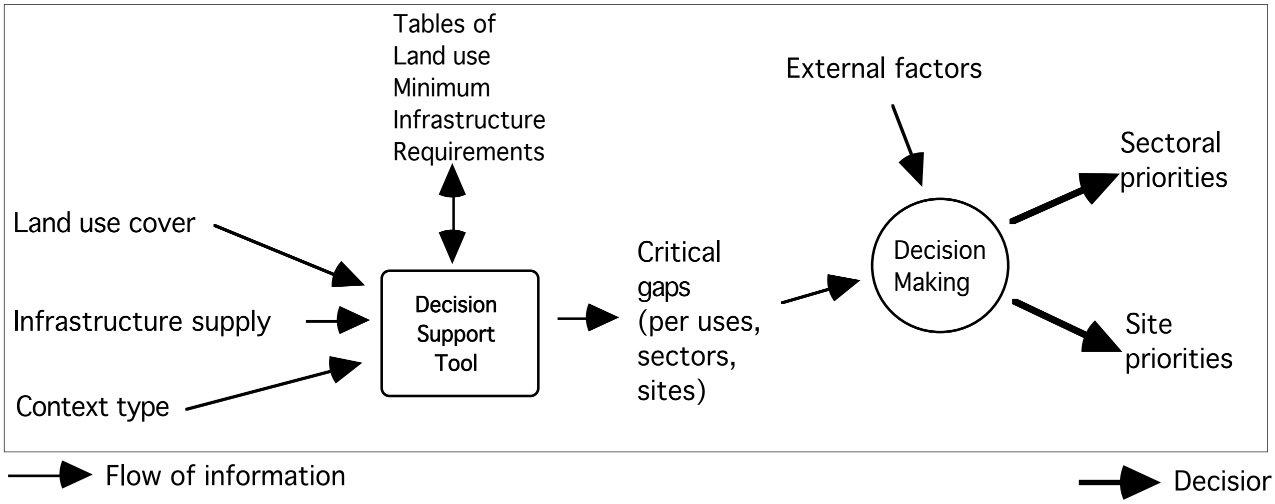

Fig. 3 Use of tool in strategic decision making on infrastructure development

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