THE ROAD LESS TRAVELLED:
SCALE IN THE ASSESSMENT AND PLANNING OF HIGHWAYS

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Cover significance:
Front: An artistic impression of a 2-lane highway – a ribbon of asphalt stretching across a pristine terrain, towards a brighter future, enabling access to many without disturbance to any. Back: In the absence of highways, vehicular movement still goes on, causing severe long term degradation of vast swathes of land. Film-strip: The storyline between the two situations – social isolation, ecological values, traditional livelihoods, intergenerational equity, and the role of remote sensing, GIS and an understanding of scale in facilitating the right balance between them – is what this thesis is about.

Cover designed by Sukhad Keshkamat, with assistance from Dr. Roel Slootweg and NE Tsendbazar.

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DISSERTATION

to obtain
the degree of Doctor at the University of Twente,
on the authority of the Rector Magnificus,
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on account of the decision of the graduation committee,
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Acknowledgements

This dissertation brings to a close a journey which started in June 2006 when, as part of my Masters research on the Erasmus Mundus programme, I first mooted the idea of developing a methodology for highway planning that could be used to align roads more sensibly and sensitively. It has been a long arduous journey and I am greatly thankful to a lot of people for helping me complete it.

To my mother and sister, my bulwarks, who afforded me the luxury of taking up opportunities without hog-tying me down with filial responsibilities - advising, guiding and being there for me whenever I needed. To my beloved granny (Aji), who I lost during this PhD and sorely miss. To my favorite aunts Atey and Lalit-maushi. To Nandika (*minii haiir*) who was always there by my side these years to share the smooth stretches, discuss work pleasurably and help straighten out the nasty kinks in life, RS and GIS. To Hindol, Bhoop and Chompsky who left, but never really left. And to Puttputt and Luttlutt, our two lovely whackos.

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I have made so many splendid friendships along the way - Ben, Christine, Sabrina (and Nuno), Andre, Prasanna, Maitreyi, Jorien, Priya, Petra, Jelle, Matt, Divyani, Sekhar, Abel, Al-Joufie, Bahman, Mila, Khan. It was always heartening to know I could count on you. Especially Ben, Christine and Prasanna, who I could especially count on to discuss ideas, read and re-read multiple drafts, share a nice wine and terrible cooking while listening to me blaspheme and vent frustrations.

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Executive Summary

The planning of the route or route alignment is a consistently grey area in highway planning, although much progress has been achieved in detailed engineering design of pavements and geometrics. Current techniques of highway route planning suffer from some shortcomings. Most alignment processes aren't spatial by nature, and so fail to address the issue of scale in planning. They also miss the use of the impacts in the planning process.

Impact assessment of highways usually occurs too late in the highway development process and therefore can only mitigate, not avoid, serious negative impacts. Impact assessment is focussed on negative impacts only, and is thus imbalanced. At the same time cost-benefit analysis, although it produces credible and salient information early in the process, is increasingly being perceived as a black-box without legitimacy and its moral relevance is being questioned. Besides this, it aggregates information into a few monetary indicators and therefore cannot address issues, such as highway planning, where indicators, relationships and effects are essentially spatial by nature.

If assessment processes are pulled upstream of the planning process, geospatial techniques (such as GIS) and geospatial technologies (such as remote sensing) can improve the process of highway alignment by furnishing rational and scientifically-derived alternatives as information to decision-makers.

Proponents in highway development projects are usually national, provincial or local governments. Therefore with a view to transparency, equitable implementation and robust public participation in the planning and implementation processes, the requirements for environmental sustainability, salience, credibility and legitimacy[1] also need to be considered intrinsically and holistically into the planning processes. However, these requirements are highly scale dependent characteristics, which force upon us the need for a

[1] Credibility: information has to be scientifically valid.
Salience: information has to be formatted for the right audience.
Legitimacy: stakeholder involvement in the process and recognition by them of their interests in the information outputs.

deeper and better understanding of scale and its effects in processes and their outcomes. The need for transparency also necessitates and highlights the need to explain and be able to negotiate the use of scales in planning.

However, despite copious amounts of research on scale, it still remains largely un-understood and usually understated in the planning and assessment processes. In research practice too it has stayed steeped in individual disciplines. A transdisciplinary perspective and understanding of scale is needed. Boundary objects - frameworks which are flexible enough to apply to across different disciplines and yet robust enough to maintain the core ideas - offer a means to understand, explain, negotiate and choose appropriate scales across disciplinary boundaries.

A boundary object in which the choice of scale is represented as a 3-dimensional framework whose dimensions consist of reality, model and data scales is proposed in this thesis. This boundary object can be used where scale choices are made in the context of space, time, as well as analytical, administrative or planning hierarchies in which space-time plays a role.

In this research, a multi-tiered SEA[2]-like assessment methodology is used to understand and identify the stakeholders and goals to be considered in the alignment of international highways at each tier – policy, plan, programme and project. Governmental planning which is traditionally meant to be hierarchically layered, with objectives and outcomes of lower tiers nested under those of higher tiers, does not usually follow such a nested approach in practice. SEA can 'force' governments to think and use tiering in their development processes.

From the perspectives of feasibility and sustainability, it is as important to consider national goals in the planning as well as international ones. At the same time, long term goals as well as short-term goals need to be incorporated, and hence the multi-tier planning system should be able to accommodate policies, plans, programmes as well as projects. Some of the goals are complex

[2] Strategic Environmental Assessment

multi-level policy goals which need to be operationalized in order to conduct geospatial analysis which can meld stakeholder concerns and priorities.

The outcomes of this planning process would be firstly networks – links and nodes which are aligned to broad policy goals. In the next lower tier, links are formed into corridors of specific widths. These corridors will be used to limit and identify route alternatives in the next lower tier, and then in the lowest planning tiers, to prioritize projects. Thus, positive impacts can be maximized and negative impacts can be minimized at each tier. The example of the corridor planning of the Millennium Road of Mongolia, the link AH-32 under the Asian Highway Network is used to demonstrate how spatial information and multi-criteria analysis can aid the objective planning of highway with coarse policy goals without losing on practicality.

As mentioned before, in conventional planning practices the assessment of environmental impacts occurs too late in the process, well after the entire route alignment is finalised. Stakeholder engagement is confined only to ranking of a few alternatives proposed by the proponent. There is too little stakeholder involvement in the actual formulation of the route alternatives. Stakeholders are thus often discontented with the planning process and agitate when the project implementation begins, stalling it. Moving the impact assessment process much more upstream - to the very starting of the route alignment planning process - can enable a balanced treatment of positive and negative impacts driven by stakeholder involvement. By addressing stakeholder concerns and priorities in the planning process, transparency and stakeholder satisfaction with the planning process can be improved much more than in current practice. For example, the use of stakeholder concerns, priorities could be used in conjunction with experts' knowledge to design better and more acceptable route alternatives within a specified corridor for the Via Baltica expressway in Poland.

Once the routes are planned the usability, operability and project prioritisation should again be taken up in more detail - the user perspectives and local (micro-) environments should form the next concerns. For example, the lack of formal road infrastructure is causing vehicle drivers to create their own tracks. As these tracks are used by more and more vehicles, they widen into dirt-roads and thence into dirt-road corridors causing enormous spatial and temporal degradation of fragile, yet socio-economically highly important, rangelands. An analysis of the practice, to identify, counter-act and mitigate them to the greatest extent possible could be used to prioritise development and mitigation projects, ideally the lowest tier in a proper highway planning structure.

This research proposes and demonstrates a holistic methodology for planning of rational and scientifically derived highway alignment alternatives through different geographic and administrative scales and through the 4 planning tiers of an SEA-like structure. It encourages consideration of both positive and negative impacts in the planning of large highways and therefore encourages objective and more transparent practices in highway planning practice. By bettering the practice and outcomes of the planning process, stakeholder satisfaction, environmental protection and economic benefits from the projects can be greater than before without exceeding institutional capacities.

1 Introducing planning and assessment of highways

Planning, assessment and setting the stage.

Highlights

Highways have both positive and negative impacts.

Current techniques of highway route planning suffer from some shortcomings. Most aren't spatial by nature, and so fail to address the issue of scale in planning. They also miss the use of the impacts in the planning process.

Impact assessment of highways usually occurs too late in the highway development process and therefore can only mitigate, not avoid, serious negative impacts. Impact assessment is focussed on negative impacts only, and is thus imbalanced.

If the assessment processes are pulled upstream of the planning process, geospatial techniques (such as GIS) and geospatial technologies (such as remote sensing) can improve the process of highway alignment.

1.1 Introduction

This research is about effect of scale in the planning of environmentally (socially and biophysically) sustainable linear infrastructure such as highways, electrical-transmission lines, pipelines etc. The research aims to provide stakeholders, planners and decision makers with better and more transparent techniques for the generation of alternatives in alignment planning practice. In addition it could also help the practice of environmental assessment, usually a mandatory regulatory process which should precede and run parallel to planning, implementation and monitoring exercises.

Linear infrastructure development projects are the focus of this research. Linear infrastructure has the following notable characteristics which makes them particularly important compared to other human interventions. These are:

1. They are built for traversing considerable uninterrupted longitudinal distances. Due to this, they interface with a variety of environmental conditions, both social and bio-physical, along their trajectory.
2. Although their lateral dimensions are small compared to their longitudinal direction, their constructions (except for overhead transmission lines) are known to create a fragmentary and divisive effect on the landscape, hydrology, community and wildlife habitats.
3. Due to the distributed nature of such projects, assets, resources, problems and impacts (both positive and negative) tend to be spread/dispersed over significant distances.
4. In addition to dispersed impacts, by virtue of their spatial characteristics, linear infrastructure projects also deliver localized impacts (similar to point infrastructure) at two or more locations along the route.
5. Linear infrastructure like highways, railways, canals and pipelines may serve as barriers, conduits, habitats, sinks or sources in the environments that they run through (Burel and Baudry, 2003).
6. Unintended impacts, both negative and positive, can be delivered far from intended location of the intended positive impacts.

It is due to these reasons that management and impact assessment of linear infrastructure projects requires highly specific know-how, skills and understanding.

Highways, the most versatile and prolific form of transport, are a specific form of linear infrastructure projects. Since the onset of the Industrial Revolution, mankind's relentless drive for economic growth led to pressure to construct, widen and extend highways (Banister, 2002). The jet-age did not reduce this demand; it fuelled it and magnified it into a demand for development of transcontinental highways as a means of globalization of trade and commerce. The growing realization that highway development brings in social progress and poverty alleviation, in addition to economic growth has led to governments including highway development as a key point of their growth strategies (Serven et al., 2004, World Bank et al., 1997, World Bank, 2003). It also led the United Nations to usher in the age of "*giga-projects*"- ambitious transportation projects stretching thousands of kilometers, such as The Pan-American Highway, The Trans-European transport network, Asian Highway network and The Trans-African Highway.

Growth, however, is seldom achieved without 'collateral damage' – a price, often heavy, in terms of negative environmental impact. The World Bank's roads and the environment manual (World Bank et al., 1997) divides the impacts from roads into 3 categories:

1) Direct Impacts
2) Indirect Impacts
3) Cumulative Impacts

Examples of these impacts from the development of the Trans-Amazonian highway are shown in Figure 1.1.

Based on their nature they can be further broken down into positive & negative impacts, random & predictable impacts, local & widespread impacts, temporary & permanent impacts or short-term & long-term impacts. Due to the diversity and range of these impacts on the bio-physical, social and economic fronts, planning and assessment for road developments should be done minutely and yet, holistically. Unfortunately, this is usually not the case, often despite the best intentions of the planners.

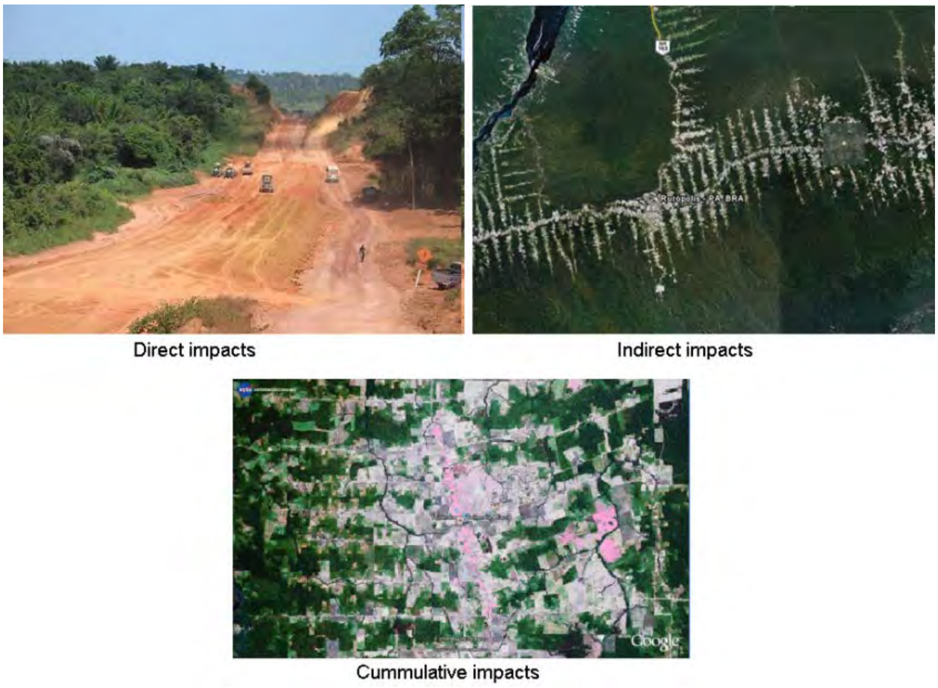

Figure 1.1: An example of impacts from roads – The Trans-Amazonian Highway in Brazil (Source: Adapted from Butler (2008))

Considered in a wider perspective, it will be seen that roads are the biggest man-made elements influencing anthropogenic change in the natural environment. The GLOBIO map of Asia (Figure 1.2) shows that anthropogenic change is strongest where road networks are denser and better developed. A closer look shows clearly that human-induced change is strongest near the road and decreases in intensity with increasing distance from it. In places with a dense ("well developed") network of roads, there is no opportunity for the change-effect to be decayed. Thus natural areas are being degraded and making way for quasi-urbanisation.

Figure 1.2: The GLOBIO model for Asia, showing the effect of anthropogenic activities on the natural environment. (Adapted from: Nellemann et al. (2001))

Chomitz and Gray (1996) modelled land use and land cover change with the development of roads. Reduction of natural habitats, the world over is considered a key threat to biodiversity conservation (Geneletti, 2003). Linear infrastructures, in particular roads, are considered as the largest contributor to this threat (Coffin, 2007). The Figure 1.3 gives an indicative idea of the typical effects and effect ranges of a "typical highway" on the adjacent biophysical environment.

The figure is however not comprehensive in terms of the effects, nor is it descriptive of different forms of highway development. Rajvanshi et al. (2001) and Cyglicki (2005) amongst others, are of the opinion that although the positive impacts of a new-build highway project are the same as a highway upgrade project, the negative impacts differ vastly. In the social spectrum too, the negative impacts may be much more than the positive.

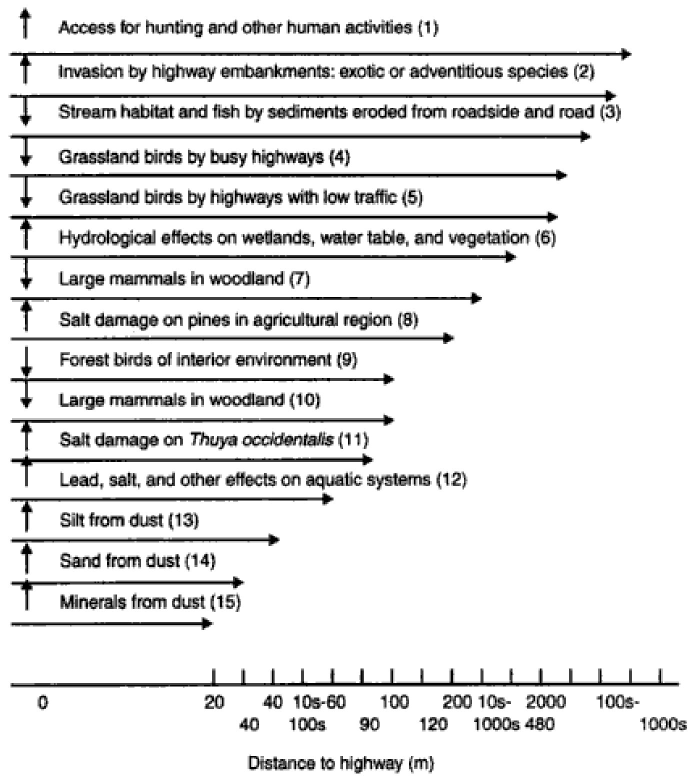

Figure 1.3: Approximate influence distances of a road on the biophysical environment (Source: van der Zande, 1980)

Reduction of natural habitats the world over is considered as a key threat to biodiversity conservation (Geneletti, 2003). Linear infrastructure, in particular roads, is considered as the largest contributor to this threat (Coffin, 2007). As described earlier, highway impacts can be divided into five categories, however the two main effects on the ecosystem are the edge and barrier/fragmentation effects. In addition to being movement barriers which isolate populations and lead to long term population decline (Bekker and Canters, 1995), roads result in increased wildlife mortality, verge effects on flora, habitat loss and degradation, disturbances due to increased human activity, (air, sound and light) pollution, altered microclimate and hydrological conditions (Dunne and Leopold, 1978, Forman, 2003, Jones et al., 2000). Figure 1.4 schematically describes some of the effects of roads on the ecosystem.

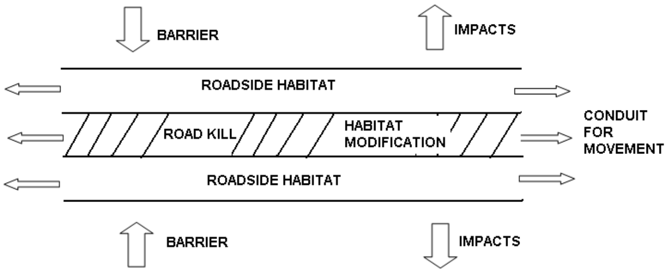

Figure 1.4: Schematic representation of biophysical impacts of a road (Adapted from (Rajvanshi et al., 2001)

Roads are also known to have direct and indirect negative impact on social fabric, cultural and archaeological heritage, traditional livelihoods, roadside developments and community health (Slootweg et al., 2001). Yet concurrently roads open up new frontiers for settlement and development of the region; bringing in better access to medical, educational and social services, income generation (through trade, tourism or industrialization), increased capital inflow, commercial development and associated appreciation of land value. Hence they could be harbingers of economic progress to the region (Kansky, 1963, Taaffe et al., 1963). Thus, to claim that roads only have only negative effects would be incorrect. They are built because they have positive impacts (advantages) and the business as usual (BAU) baseline should be assessed before passing this judgement. Hence, it must be our strenuous effort to derive maximum benefit for the costs that we have to pay – to optimize the alignment to the greatest extent possible, in terms of all costs incurred by us, not just the tangible, land and construction costs.

This research aims to contribute on three fronts –

a) To improve upon current planning practices,
b) To improve upon current impact assessment practices and
c) To further contribute to strategic thinking in infrastructure development processes.

From the point of strategic thinking, the choice of scale plays an important role in the models, assessment, stakeholder engagement, analytical techniques and data usage of spatial planning processes. Further stakeholder concerns and priorities change at different scale levels and if one wants to address the issues of legitimacy and equity in a salient and transparent manner, one must investigate the planning at different scale levels.[3]

1.2 Highways - Planning and impact assessment

In the previous sections, it was discussed how highways impact the environment through which they run. However, what is not as often realized is that, the environment will also have an impact upon the roads themselves, which will have important implications for safety and spatial connectivity. In addition, the socio-economic goals of the project need to be fulfilled in order to realize the capital and land investment made in them.

Highway construction is a fundamental basis of development, as access to resources and expanding markets is vital to economic growth. In this current era of global economies, this is especially true of trans-national highways. There is an increasing expectation from these mammoth highway projects to serve as support for poverty alleviation initiatives. Thus it has become necessary to use an institutional management tool such as highways in a measured, rational and well planned manner, in order that maximum economic advantage can be gained at the lowest environmental cost. This is also in line with the opinion of scientists, impact assessment practitioners and engineers, who are now turning away from the *mitigation tactics* of yesteryears to *avoidance strategies*, a more pro-active approach.[4]

Although, this is a highly positive turn of events, this change of approach brings pressure upon the planning process to work synergistically with the impact assessment process within the pre-construction development stage. Traditionally, these processes have always been independent of each other and quite disparate from each other. In this introductory chapter, the working

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[3] Another complication to this is the deciding of the temporal resolution and extent i.e. the time scale of the planning.

[4] All human interventions will have consequential negative impacts on the existent environment. Avoidance of “as many as possible” should be the focus of a healthy planning process. Mitigation tactics should be considered only when all reasonable means of avoidance have been exhausted or eliminated as unviable.

of these as separate units will be described to reveal the justification to merge these two functions into a single holistic methodology.

1.2.1 Current practices in road planning

Planning of new highway routes, is presently a predominantly “experience-based” subjective process, extensively dependent on “local familiarity” of the planner with the region, availability of maps, political motives and non-overt business influences. Haynes et al. (2005) mention that even with the vast advances of computer aided GIS techniques, highway planning has remained not much more than drawing a line on a map from point to point to point. Based on one or more tentative alignments formulated by such methods, a coarse reconnaissance survey is carried out and the alignments are refined or eliminated. The planning of highway upgrade projects is not vastly different. Since some development and land-use patterns already exist, political influences and real-estate interests usually dominate the planning. Social considerations such as existing roadside commerce, habitations, possible displacement of populations etc. also play a very important role. Since a road already exists, reconnaissance surveys may be even coarser than in a new-build highway (also known as Greenfield projects).

Much of the theory in road planning sees the process as one managed by technical, managerial and scientific rationality, which entails a stepwise, systematic and thorough sequence of information gathering and decision-making steps, which include:

1. Goal definition – broad (community values), specific (objectives) and measures of effectiveness.
2. Identification of needs and their prioritisation.
3. Development of alternative solutions
4. Evaluation of alternative solutions
5. Rational selection of alternatives by the decision maker.

This school of thought incorporates political activity in the goal definition (1), (2) and the alternative selection (5) stages. Figure 1.5 shows the main steps in such a planning process.

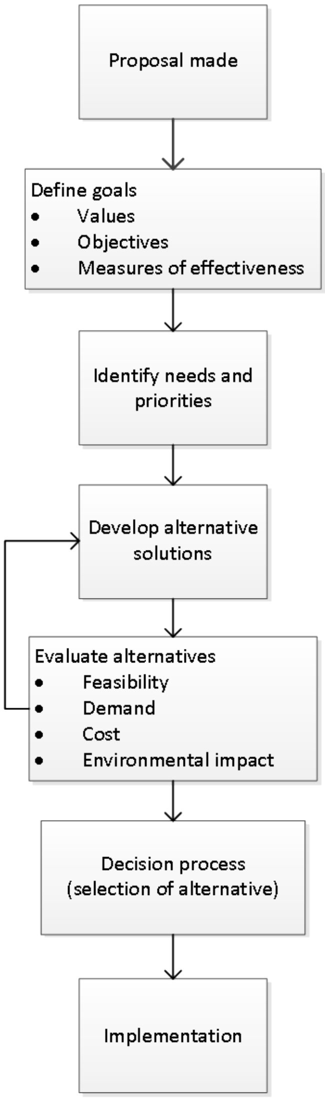


Figure 1.5: The theoretical planning process (From Banks, 2004)

Banks (2004) also states that it is generally known in practice that, highway alignment processes have much stronger links to political parleys and perspectives – political rationalities, overt as well as covert, play a strong role. However, in order to maintain public credibility as well as ensure the feasibility of the project, technical rationality stays intrinsically connected. Thus technical and political influences dominate the planning in reality (Figure 1.6).

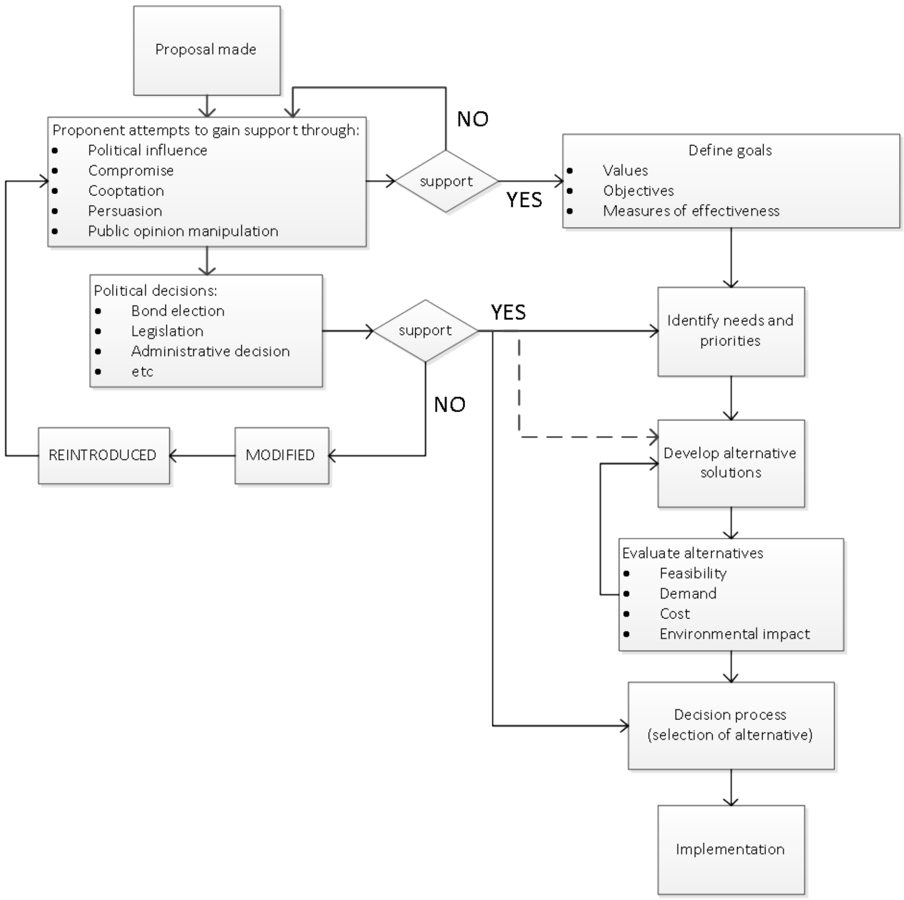


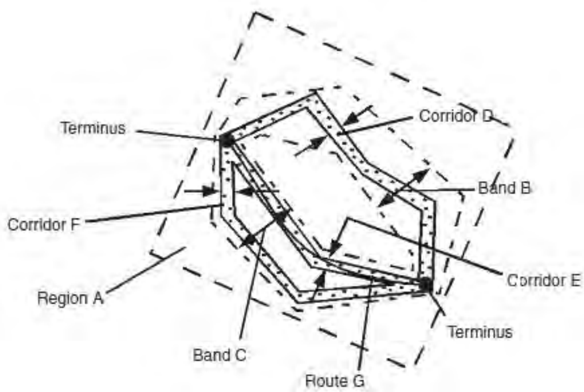
Figure 1.6: The realistic planning process (Adapted from Banks, 2004)

The formulation of alternatives lies at the very core of good practice development planning and impact assessment, and underpins good decision making. At this juncture, it is necessary to explain the key concept of alternatives and its importance to rational decision making. This concept underlies "good practices" in any development planning strategy (Kulkarni et al., 1993). Rational behavior itself was described by *Simon (1950)* as, "*…the selection of alternatives that are conducive to reaching preselected goals, and a rational decision is one that is based on (and consistent with) values, alternatives and concerns that are weighed by the individual or group, making the decision"*. To add to this, *Diesing (1962)* opined that *"… the provision of proper alternatives, based on intelligent insight rather than luck, is imperative to the process of rational decision making*".

Keeping this in mind, we now explore the planning and impact assessment processes as they are currently, and traditionally have been, practiced. The World Bank's Operational Directive OD 4.01 on environmental assessment for roads (World Bank, 1996) calls for systematic comparison of the proposed investment design, site, technology, and operational alternatives in terms of their potential environmental and economic impacts. It goes on to emphasize that "…*a thorough, unbiased and transparent assessment of investment alternatives from an environmental and social perspective (as well as a technical and economic standpoint) is one of the most important contributions EA can make to improving rational decision-making".*

Usually, only two or three alignments (in rare cases, more) are shortlisted for further consideration and a "preferred alternative" is identified. These alignments are then used as the basis for a preliminary design, cost estimation, impact assessment (if required), stakeholder involvement (if conducted) and decision making. Only when a decision is finalized on which of these alignments is to be executed, do technical design processes take over. Detailed engineering surveys (soil, topography, utilisation estimations) are conducted and mitigation measures (such as animal passages), bridges, ancillary structures (such as acoustic barriers, pedestrian crossings, intersections etc.) that will be needed are identified. Engineering design is developed according to these outcomes and project costs are estimated.

The book Highway engineering by O'Flaherty (1988), which is often used as a fundamental textbook in highway engineering courses, describes succinctly how the ideal alignment process should proceed. The following text-box is drawn from the book. In general, once the need for a major road has been justified by the transport planning process, the approach to selecting an appropriate route location can be described as a 'hierarchically structured decision processes'. The first step in the location process requires fixing the end termini, and then defining a region, A, which will include all feasible routes between these two points; in a non-urban setting this region will often be, say, one-third as wide as it is long. The region is then searched using reconnaissance techniques to obtain a limited number of broad bands, B and C, within which further refining searches can be concentrated; for a rural motorway, for example, such bands might be as much as 8–16 km wide. Within these bands, further reconnaissance-type searching may result in the selection of corridors D, E and F, each perhaps 3–8 km wide. A comparison of these corridors may then suggest that E will provide the best route, and route G is then generated within it; typically, this route could be 1–1.5 km wide in a rural locale. The next, preliminary location, step is to search this route and locate within it one or more feasible alignments, each perhaps 30 m wide and containing relatively minor design differences. These alignments are then compared during the final location phase of the analysis, and the most suitable one is selected for structural design and construction purposes.



A hypothetical route location.

Note that the above process involves continuous searching and selecting, using increasingly more detailed information and data at each decision-making stage. 'Tangible' considerations that might influence the selection process at any given instance could typically include topographic, soil and geological survey data, land usages and population distributions, travel demands and road user costs, construction and maintenance costs, and safety factors. 'Intangible' considerations of a political, social and environmental nature which require extensive public consultation may also have to be taken into account before final location decisions can be taken.

As is seen, these alignment alternatives are formulated subjectively[5] and in a non-transparent manner (Steinemann, 2001) and stakeholder involvement, if at all, (UNESCAP, 2002) occurs too late in the process and is limited to "*selection of the best alternative from the given alternatives*". The orientation of such an approach is thus on mitigation rather than avoidance and it is quite common that stakeholder dissatisfaction with the entire planning process runs high and confidence in the decision making process runs low. For a major project, this discontent may usually surface, often through litigation and/or strikes, once the contractor begins construction, thus resulting in project delays, cost-escalation etc. In a democratic society, unless the project is forced through *as-is* by the government, partial re-routing or additional mitigation measures must often be conceded by the decision makers. Usually not acknowledged, this is a fault of current planning processes that can, and should, be addressed.

With increasing use of GIS in transport modeling, travel demand identification, trip theory etc., economic potential of highway developments is shifting slowly from the realm of scientific research into practical use (Hensher and Button, 2003), but this trend, in regional highway development, is mainly restricted to a few European Union and North American countries and does not yet seem to have found widespread use in developing countries, in Asia for example UNESCAP (2006a).

In addition to this author's professional knowledge used to describe the process above, a literature review was carried out to identify documented references to current techniques used by planning practitioners and authorities, but revealed little additional information. Typical phraseology used by planners and authorities to avoid detailed explanation of how the alternatives are generated are, for example:

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[5] Subjectivity is an acceptable inherent characteristic of evaluations, and scientifically valid, as long as its use is made explicit during the evaluation process *(Wilkins, 2003),* and its application delayed until "all avenues of objective measurement have been explored" *(Treweek, 1996*).

a) *"…alternate alignments are based on thorough ground reconnaissance and meet the prescribed design standards. Peer review of the alignments will be carried out, if needed." (National Highways Authority of India (Works manual), 2006; MoRTH-India (The Orange Book), 2001).*
b) *"…the result of thorough analysis of technical, environmental, economic and supply security factors conducted over many years." (Nordstream, 2008).*
c) *"…conceptual route alternatives were developed which best avoided the constraints identified within the study area." (Ontario Ministry of Transportation, 2002).*

The website of the *German Ministry of public works (Ministerium für Bauen und Verkehr)* reveals one of the best documented complete descriptions - *"Starting point and endpoint of the road - Basic route the road will follow - Links with the existing road network - Interfaces to other modes of transport (e.g. local public transport facilities, Park 'n' Ride). - Characteristics of the stretch of road - Approximate position in relation to contiguous or neighbouring built-up areas, protected areas or areas constituting potential sources of risk - Whether the road will pass under bridges, over dams, through clearings or tunnels, in cases where such considerations are necessary and possible for judging the impact of the project at the particular planning stage."*

However, despite this apparent lacuna in guidelines of highway route planning practice, research into developing, investigating and documenting scientific techniques of highway route alignment and network design has been carried out only by a handful of researchers such as Jha et al. (2000, 2000, 2004, 2005, 2007), Parker (1977) Trietsch (1987a, 1987b), Steenbrink (1974), Kulkarni (1993, 2004), Akinyemi et al., (1989, 2002), Grossardt and Bailey (2001, 2001, 2007), and the US FHWA. Most of this research has an engineering focus and considers highway alignment from the perspectives of ease of design, geometric detailing such as gradients, curves, super-elevations and road furniture, cut-and-fill optimization or construction and operating cost efficiencies. Very little of it relates to balancing the environmental impacts of the project, the most important aspects to ensure the environmental, economic and political sustainability of the highway infrastructure development.

Impact optimization techniques consist of taking the hitherto disparate areas of assessment and planning and integrating the two into an assessment-based planning process. In order to understand this reasoning better, it is necessary to know more about impact assessment.

1.2.2 Current practices in road impact assessment

Impact assessment, simply defined, is the process of identifying the future consequences of a current or proposed action. Impact assessment, as we know it today, first came into mode in the late '50s in the form of Environmental Impact Assessment (EIA) as a means to enable planners and decision makers to take into account information about the environmental and social impacts of their projects. In theory, good planning takes these issues into account, but as shown in the previous section, it is not usually the case in practice. In this section the salient features of EIA, Strategic Environmental Assessment (SEA) and Cost-Benefit Analysis (CBA) will be discussed through a literature review of relevant contemporary publications.

<u>Environmental impact assessment (EIA)</u>

Environmental impact assessment is defined as the process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made (Glasson et al., 1999, Petts, 1999, Shepard, 2005, Wood, 1996, Wood, 2003b). Apart from assessing impact by experts, EIA is designed to provide stakeholders with information on the consequences of the new developments, and involve them in the impact assessment process, in order to provide salient information to decision makers. In an effort to force the consideration of these impacts in decision making, the National Environmental Policy Act (NEPA) became a legal requirement in the US, in 1970, for any planned project (Wood and Djeddour, 1992). This eventually led to EIA as a statutory requirement for any major project, in almost every country today (Dalal-Clayton and Sadler, 2005).

The International Association for Impact Assessment (IAIA) the main international body for impact assessment regarding policies, programs, plans and projects, develops the codes guidelines and best practice documentation that the impact assessment professionals should use globally in their projects. It lays down four main objectives of an EIA as:

• To ensure that environmental considerations are explicitly addressed and incorporated into the development decision making process;

• To anticipate and avoid, minimize or offset the adverse significant biophysical, social and other relevant effects of development proposals;

• To protect the productivity and capacity of natural systems and the ecological processes which maintain their functions; and

• To promote development that is sustainable and optimizes resource use and management opportunities.

To reach these objectives, the IAIA also defines two tiers of EIA principles:

1. "Basic Principles" apply to all stages of EIA; they also apply to Strategic Environmental Assessment (SEA) of policies, plans and programs.
2. "Operating Principles" describe how the Basic Principles should be applied to the main steps and specific activities of the environmental impact assessment process; e.g., screening; scoping; identification of impacts; assessment of alternatives.

It is also envisaged that subsequent tiers of Principles could evolve, building on and extending the Basic and Operating Principles, e.g., "activity-specific," "state-of-the-art" and "next generation" of impact assessment principles.

The IAIA states that the EIA process "*should be applied as early as possible in decision making and throughout the life cycle of the proposed activity to all development proposals that may cause potentially significant effects, to biophysical impacts and relevant socio-economic factors, including health, culture, gender, lifestyle, age, and cumulative effects consistent with the concept and principles of sustainable development, to provide for the involvement and input of communities and industries affected by a proposal, as well as the interested public in accordance with internationally agreed measures and activities."*

The main steps of an EIA process in the IAIA best practice guidelines are shown in Figure 1.7.

Screening - to determine whether or not a proposal should be subject to EIA and, if so, at what level of detail.

Scoping - to identify the issues and impacts that are likely to be important and to establish terms of reference for EIA.

Examination of alternatives - to establish the preferred or most environmentally sound and benign option for achieving proposal objectives.

Impact analysis - to identify and predict the likely environmental, social and other related effects of the proposal.

Mitigation and impact management - to establish the measures that are necessary to avoid, minimize or offset predicted adverse impacts and, where appropriate, to incorporate these into an environmental management plan or system.

Evaluation of significance - to determine the relative importance and acceptability of residual impacts (i.e., impacts that cannot be mitigated).

Preparation of environmental impact statement (EIS) or report - to document clearly and impartially impacts of the proposal, the proposed measures for mitigation, the significance of effects, and the concerns of the interested public and the communities affected by the proposal.

Review of the EIS - to determine whether the report meets its terms of reference, provides a satisfactory assessment of the proposal(s) and contains the information required for decision making.

Decision making - to approve or reject the proposal and to establish the terms and conditions for its implementation.

Follow up - to ensure that the terms and condition of approval are met; to monitor the impacts of development and the effectiveness of mitigation measures; to strengthen future EIA applications and mitigation measures; and, where required, to undertake environmental audit and process evaluation to optimize environmental management.*

Figure 1.7: Steps in an EIA process (Source: (IAIA (International Association for Impact Assessment) and IEA (Institute of Environmental Assessment), 1999))

However, while the original intent of the EIA was to include regulations, plans, policies procedures and programmes (Wood, 2003a, Wood, 2003b), in practice it revolved only around projects (Glasson et al., 1994). This led to the growing realization that EIA occurs at the stage where most decisions have already been taken earlier during the planning process, thus leaving decision makers with the responsibility of taking a decision with very little choice – refuse, accept, or accept with some mitigation measures. The opportunity to fundamentally change the design in order to entirely avoid the harm has been taken far upstream in the process, when the full impacts of plan policy and program could not have been known, for example, the main issues, transport modal choices, corridor and alignment choices have already been made in earlier phases (Fischer, 2006, Treweek et al., 2005).

Flowcharts of the processes followed by the UK's highway authority (Boyle, 2002), *Nieuwe Ontwerprichtlijnen voor Autosnelwegen* (NOA) (Rijkswaterstaat, 2008) and National Highways Authority of India (IRC, 1988) drawn from national highway guideline documents substantiate the claim that the EIA public hearing occurs so late in the process, even in countries with strong environmental laws, that it can serve only a mitigation function at best, if at all even that. In addition, it is usually considered toothless because it is seen as no more than an analysis conducted by the proponent to obtain the necessary statutory approvals. In an effort to give EIA more strength (Arts, 1998, Arts et al., 2001), call for stronger post-facto monitoring and follow up.

In addition to the late inputs from the EIA process, the EIA process also suffers from the problem of scale (Ramanathan, 2001, Stewart-Oaten et al., 1986). The Canadian Environmental Assessment Agency (Beanlands and Duinker, 1983) comments on the issue of scale in EIA: *'If large boundaries are defined, only superficial assessment may be possible and uncertainty will increase. If the boundaries are small, a more detailed examination may be feasible but an understanding of the broad context may be sacrificed. Proponents may perceive assessments with large boundaries as onerous or unfeasible, whereas the public may think small boundaries do not adequately encompass all of the project's environmental effects'.* Joao (2002) proves through comparison of EIAs of the same project at different scales how the outcomes of EIAs can be controversially different in terms of the type of impacts found, their magnitude and significance, the type of mitigation measures recommended, and ultimately the end decision regarding the proposal. In stakeholder-based processes which would involve identification and engagement of affected parties, scale selection can have considerable influences on who is called upon to participate in the process, whose opinions are heard, in which context, and whose priorities dominate. The importance of scale and a boundary object for its understanding will be expanded upon further in this thesis.

Strategic environmental assessment (SEA)

It is due to these critical shortcomings of EIA that SEA came into being in the mid-80s (Wood and Djeddour, 1992). Although SEA was initially propounded as simply the application of project EIA principles to Policies, Plans and Programmes (PPP), it soon emerged into a means of planning that addressed:

i. larger geographical and temporal scales (Lee and Walsh, 1992)
ii. patterns rather than detail (Partidario and Fischer, 2004)
iii. higher decision levels and strategic choices (Fischer, 2006)

Saddler and Verheem (1996) define SEA as "*a systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision-making on par with economic and social considerations*". SEA thus offers the ability to take environmental, social and economic issues alternatives, and impacts into account early in the planning process and thus can considerably reduce potential negative impacts. It is a proactive instrument versus EIA, which is a reactive instrument. Partidario (2000) opines that SEA is an instrument that must be adapted to existing decision-making processes. It is more political than technical, and is related to concepts, rather than to activities with geographic and technological specifications. As a consequence, the fixed procedural steps of EIA cannot simply be copied or scaled-up to SEA. She (Partidario, 2003) then states that the aims and objectives of SEA should be to :

1. *Help achieve environmental protection and sustainable development by:*
    - *Consideration of environmental effects of proposed strategic actions*
    - *Identification of the best practicable environmental option*
    - *Early warning of cumulative effects and large-scale changes*
2. *Strengthen and streamline project EIA by:*
    - *Prior identification of scope of potential impacts and information needs*
    - *Clearance of strategic issues and concerns related to justification of proposals*
    - *Reducing the time and effort necessary to conduct individual reviews*
3. *Integrate the environment into sector-specific decision-making by:*
    - *Promoting environmentally sound and sustainable proposals*
    - *Changing the way decisions are made*

Therefore, if a sturdy and salient policy framework is in place, with strong and timely communication between different levels, an SEA process can help articulate across sectoral policies and institutional contexts, providing credible and feasible strategic options which allow incremental decision support, based on values which are comparable at each geographic, hierarchical, analytical or administrative level (Partidário, 1999). Figure 1.8 expresses this using the example of one of the Mongolian Asian Highways. It shows how intent can be translated from concept to implementation through the different planning instrument levels of policy, plan, programme and project. The arrows to the right indicate possible options and the green arrows indicate the (possible) considered option and how it feeds back into the next level below it.

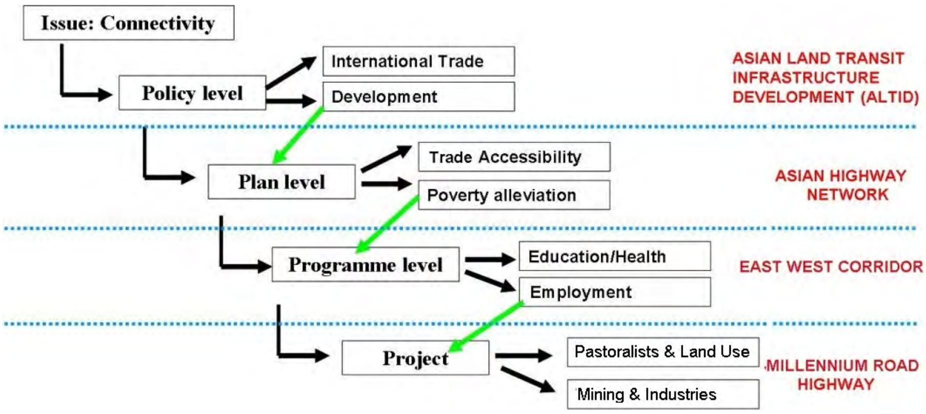

Figure 1.8: The issue of connectivity translated to a regional highway project. EIA occurs only at the lowest level - the project. Only SEA can cover all the upper (higher) levels efficiently (Source: adapted from Slootweg & Looijen, 2007).

SEA can be integrated into the planning process when proponents see it as a way of thinking that enables better decision making, or SEA can be done separately when proponents are forced to do it by law (for example, EU directive 2001/42/EC). The former is always better; the latter is at least a minimal guarantee that all possible alternatives will be considered early in the planning process. From Partidario (2003) we see that the main forms of SEA, or the so-called SEA family, are:

1. *Policy SEA*
    - *Policy Impact Assessment – environmental assessment of policy proposals to Cabinet approval (Canada)*
    - *Environmental-test (e-test) - assessment of government legislation proposals (the Netherlands)*
    - *SEA of governmental proposals - assessment of government legislation proposals (Denmark)*
2. *Regional and Spatial Planning SEA*

- *Regional EA - evaluation of regional environmental and social implications of multi-sectoral developments in a defined geographic area, over a certain period (World Bank)*
- *SEAn (Strategic Environmental Analysis) – based on community involvement applies SEA in developing countries (SNV - the Dutch Aid Agency)*
- *Environmental Appraisal of Development Plans – assessment of planning policies as council level, with main biophysical insight (UK)*
- *Sustainability Appraisal of Regional Planning – assessment of regional policy proposals, attempting a broader environmental sustainability approach (UK)*

3. *Sector Planning and Programme SEA*
   - *Environmental Overview - applies to the formulation stages of programmes, leads to early identification of environmental and social impacts and opportunities and incorporation of mitigation measures into programme redesign (UNDP)*
   - *Sectoral EA - evaluation of sector investment programmes involving multiple sub-projects; integration of environmental concerns into long-term development; and investment planning or the evaluation of sector policies (World Bank)*
4. *Regional, Spatial and Sector Planning and Programme SEA*
   - *Strategic EIA – SEA applied to spatial plans and programmes using the project's EIA procedure (the Netherlands)*
   - *Programmatic environmental assessment - process of evaluating groups of actions related geographically or having similarities of project type, timing, media or technological character (USA)*

The exact process of an SEA can vary depending upon the type and use of the SEA. However in general the following steps are followed (Dalal-Clayton and Sadler, 2005):

1. Proposal: Establishing the need for the intervention and its objectives.
2. Screening: Establishing the need for an SEA and if so, at what level.
3. Scoping: Identifying important issues and impacts to be addressed.
4. Information: Assembling environmental information and identifying key indicators.

5. Formulation and consideration of alternatives: Identifying and comparing the range of alternatives including the best practicable environmental option.
6. Impact analysis: Identifying, predicting and evaluating the effects of the proposal and the main alternatives.
7. Significance: Determining the importance of the residual impacts and if appropriate, relating these to other benefits and costs.
8. Mitigation: Identifying measures to avoid, reduce, mitigate or offset the main impacts identified.
9. Reporting: Describing the environmental impacts of the proposal and how they should be addressed.
10. Decision making: Approving, rejecting or modifying the proposal with reasons for decision.
11. Monitoring: Checking to see if the implementation is in accordance with approvals.

Transport related SEA can be conducted in one of 3 manners:

i. The most common, a top-down approach, i.e. the results of broad level objectives and decisions are filtered down to the nested local level objectives, like for example, the Dutch transport planning system.
ii. A bottom-up approach, i.e. results of local level decisions are stitched together and merged to generate higher level objectives, like for example, the German transport infrastructure planning system.
iii. A mid-out approach, i.e. decisions of mid (regional) level planning are passed down to local governments to fit their plans into, while being conveyed to national governments to frame the federal frameworks, like for example in the U.S. highway planning system.

Fischer (2006), Partidario (2007), Joao (2007), Pemberton (2000) etc. discuss extensively the top-down approach, showing how at the stage of policies decisions are being taken at large extents, with coarse resolutions and there are many choices. As the assessment goes down to the next lower tier (Plans), the choices are fewer, the assessment becomes more concentrated and focused, and so on, through programmes to projects. EIA is conducted at the project stage, during which a lot of detail can be assessed, but the scope is highly limited and so are the choices. This is represented in Figure 1.9.

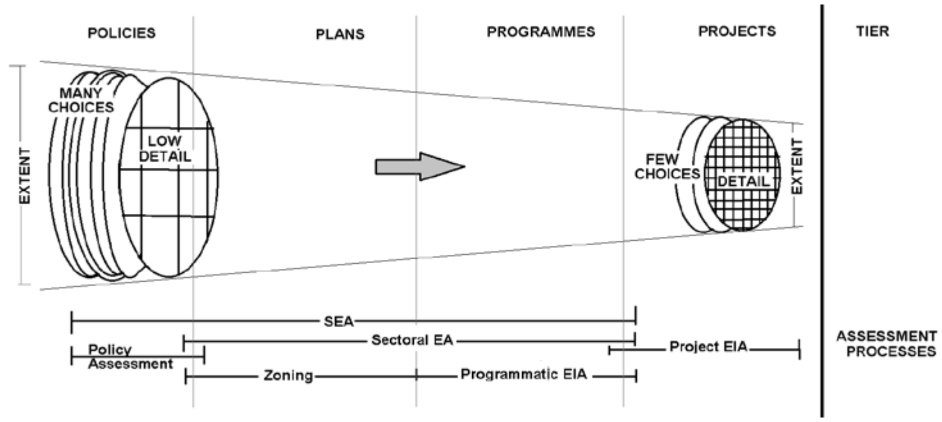

Figure 1.9: Processes and product characteristics of an Environmental Assessment.

As seen in the above project, SEA is encompasses the policies, plans and programmes tiers. (Arts et al., 2005) posit that the project tier is a missing link if the benefits of SEA thinking are to percolate down to the actual implementation of project on ground. Coming from the opposite direction, (Partidario and Fischer, 2004, Partidario and Arts, 2005) echo this position by seeking better follow-up in SEA. This research too finds it necessary to include the project tier in order that all planning scales are assessed and addressed.

Cost benefit analysis (CBA)

CBA, defined by Prest and Tuvey (1965) as a practical way of assessing the desirability of projects, is the enumeration and evaluation of all the relevant costs and benefits using a long and wide view on a common numeraire, i.e. money (Nijkamp et al., 1990). CBA is usually considered an indispensable part of the evaluation of any new transport project, in most countries and development banks. CBA forms one of the many techniques that can be used in a SEA process, however since it is a commonly popular technique, which has its own following as an independent process, it is discussed here separately.

In theory, under the CBA methodology, all potential gains and losses from a proposal are identified, converted into monetary units, and compared on the basis of decision rules to determine if the proposal is desirable from society's standpoint. A comprehensive evaluation of this type of project should ideally take into account the investments to be made in terms of finances, land and other resources, but also its potential effect on human lives and the environment. Also considered in the evaluation should be the impact on future generations and the welfare of different socioeconomic groups. Once all relevant information has been gathered, properly quantified, and compared using such methods as net present value, internal rate of return, and/or benefit-cost ratios, the analyst decides whether the proposal is beneficial from society's point of view (Nas, 1996). However, although notable progress has been made in valuing some benefits of transport projects, such as travel-time savings, we are struggling to identify monetary values at the individual project level for many environmental attributes and ecosystem services, such as changes in open space, noise, air quality, greenhouse gas emissions etc. (Daniels and Hensher, 2000).

The costs and benefits of transport have spatial and temporal dimensions, but also hierarchical and analytical dimensions. Generally, the benefits of transport activity are linked to the source and destination points of trips. So are the direct costs of that transport. However, the so-called external costs, including those of an environmental nature, arise along the way. Thus they are borne by stakeholders who are spatially separated from those who reap the benefits. This is a general feature of transport economics and not specific to sensitive areas[6]. Usually, transport planners justify this inequity by "internalisation of external costs", i.e that this does not generally pose a problem of principle because of a certain averaging effect: most regions both give rise to transport and suffer from the side effect of transport caused elsewhere.

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[6] Sensitive areas are defined as areas that are more susceptible to negative impacts than the general average (*European Commission's Directorate-General for Environment, 2004*). They may have a soil type that reacts more strongly to acidification than elsewhere, they may be particularly rich in biodiversity that is threatened from human activity, they may have rare and fragile landscape characteristics etc. What is often not considered, and will be considered here, is that "sensitive" is not necessarily a bio-physical or ecological parameter only, it can also be social. In this sense, human settlement areas, whether urban or rural, are obvious candidates for being seen as particularly sensitive or particularly affected areas.

In regions of homogenous land-use and economies or in geographically small scale investments, this approximation may indeed be justified. However, quite often this balancing effect does not occur, such as busy transit corridors, crossings of natural barriers or long distance highways. In these cases, a more elaborate spatial analysis should take into account the spatial separation of benefits and costs. A central issue here is the fact that a corridor of limited length is generally much smaller than the geographical areas that it connects. It is these areas where the demand for transport activity and the economic benefits linked to it, occur. Hence, these economic benefits are likely to outweigh the environmental costs that arise inside the corridor, even in the case of large-scale local damage there. Thus, simply comparing total costs and benefits irrespective of their spatial attributes may not be sufficient to address this local damage.

A methodology that has several shortcomings and as many opponents as followers, CBA is most favored by utilitarian economists, but has received greatest criticism because it attempts to monetize social criteria such as human and ecological values and concerns which can never be indisputably monetized (Nas, 1996, Quinet and Vickerman, 2004). Other major flaws include aspects such as discounting the future at current market values, tax-distortions, distribution issues, measurement problems etc. (Nijkamp et al., 2003). It is however the author's opinion that the critical flaw of this method of analysis which renders it unsuitable for highway route planning is that it is not spatial by nature. Thus a CBA without a means to integrate the costs and benefits into actual generation of alternatives can only serve to justify, or discard, an alternative or project. Worse still, it is "a black-box exercise of experts", with little or no stakeholder involvement, thus at the grass-roots level, stakeholders will often consider its outcomes with suspicion. At the same time, most decision makers will also not understand the way in which the results and figures were derived.

However, with the advent of SEA in transport, stronger efforts are being made to give it stakeholder legitimacy. CBA research in fields that would be of use to SEA necessarily must embrace new ideas, especially those that widen and coarsen the assessment, often wholly opposite to conventional CBA practice. Bruzelius et al. (2002), Hanley (1993), Kilijoniene (2010), Laird et al. (2005), Metz, (2008), Snieska and Simkunaite (2009), Willis et al. (1998) offer some exciting examples of new approaches in CBA that try to build stronger connections between CBA and SEA. Kulkarni et al. (2004) particularly, propose an interesting form of CBA based on Daly's steady state economy concept – Need-Based Project Prioritization, a hybrid form between cost-effectiveness analysis and cost-based analysis, which is suited for use at coarse and broad scales.

CBA also suffers dichotomies of scale similar to other disciplines. Dopheide et al. (2011) mentions that SEA and CBA are "a world-apart, although parent and child", and lays the blame on the issues of scale – resolution and detail, spatial, temporal and spatio-temporal. He echoes the view of Molenaar (2005), who reflected on the uncertainty and accuracy of CBA estimates with reference to the stage at which CBA is performed in the planning or assessment process, attributing the unrecognized and non-quantifiable costs to level of detail (granularity) and extent (Figure 1.10).

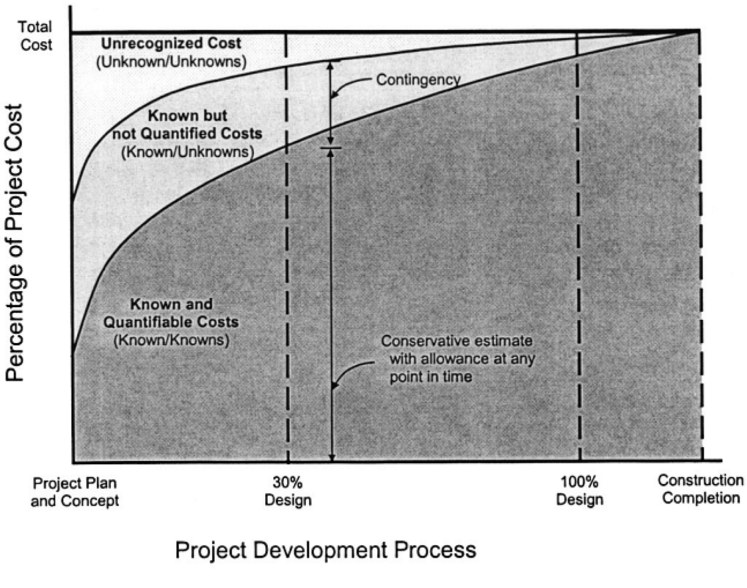

Figure 1.10: A conceptual figure of CBA development as the project progresses (Source: (Molenaar, 2005))

1.3 Planning powered by integrated spatial assessment

There is a need for an integrated approach to planning which can address societal values and beliefs by ranking preferences, and which can summarize and characterize these conditions by describing those using quantitative and qualitative environmental data. This facilitates sustainability-oriented multi-objective, multi-criteria decisions under conditions of uncertainty. GIS enables planners to have a better visualization, understanding and analysis of spatial relationships. At the same time it provides ease of use and speed of execution of iterative (or repetitive) tasks in planning processes. However GIS data of the required scale and quality is not always readily available. In addition there may be copyright, privacy or cost issues. Collecting such data for individual projects can be prohibitively resource intensive, in terms of time as well as cost. Remote sensing, particularly satellite remote sensing data, is in recent years becoming increasingly easily available in a range of scales, types and coverage. It offers a convenient and cost-effective alternative of acquiring and/or generating spatial data which can be readily used in a GIS. The sections below will elaborate how the goals of this research are closely linked with an ideal implementation of an SEA process (Figure 1.11).

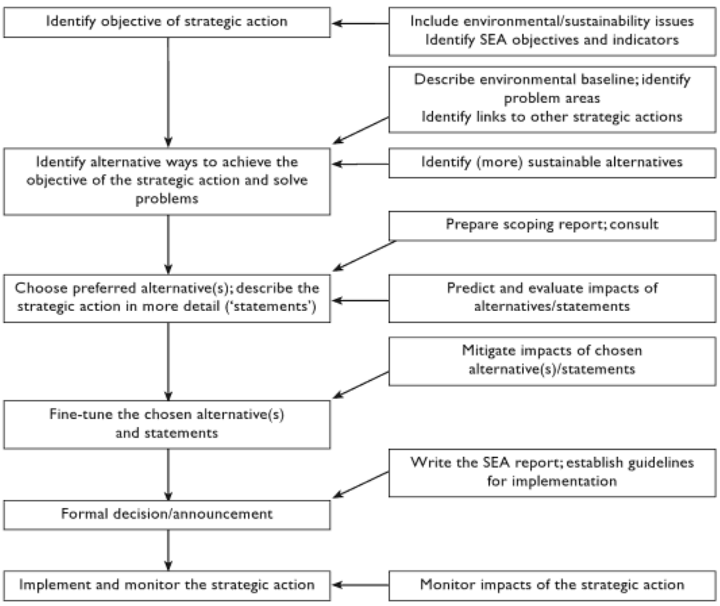

Figure 1.11: Links between SEA and top-down decision making processes in a proposed intervention (Source: (Therivel, 2004))

1.3.1 Improving upon current planning practice

Reflecting a commonly held view in highway planning, O'Flaherty (1988) remarks that "*road alignments should most preferably be routed through low-cost, relatively undeveloped, lands because in these locales basic engineering and construction cost considerations normally dominate analyses once the traffic planning need has been established and accepted – and provided that environmental issues are not of major concern. The problems become more complex and 'non-engineering' issues become more prominent as a route is sought through well-developed rural lands, and when interactions with existing roads and built-up areas have to be taken into account. The problems are normally at their most complex in and about major urban areas where community aspirations, interactions with existing roads and streets, and economic, environmental and planning issues become critical.*"

Even when it is not explicitly stated, this is often the most common view held by highway planning authorities the world-over. However, from the stakeholders' or environmentalists' perspectives such opinions only serve to confirm that highway design is dominated more by priorities of expedient design and implementation rather than environmental sustainability. However, notwithstanding this, this research will go by the precept that it should be possible to generate alternatives, not based on expedient design, but on widely held priorities i.e. 'visions'. For example, an alternative based on a vision that minimizes ecology-loss along its route, or maximises economic-growth, or eases construction, or places safety first (in the case of hazardous material transport) or simply a balanced vision alternative which just considers all priorities as having equal importance. For a decision to be based on a rational array of alternatives, the alternatives should have been designed from the intent to actualise these visions.

At a finer level of planning, current techniques can either avoid an area or move towards it, but cannot weigh/compare the two to arrive at an optimal intermediate choice. Further since it takes up one issue at a time along its path, it is not holistic i.e., it cannot deliver a route that has minimal cost impedance in terms of the *entire route*. Thus the alternatives generated by current techniques, however meticulously and honestly analysed, are inherently non-transparent and essentially sub-optimal.

To worsen this situation, stakeholder participation in conventional planning techniques is limited to final choice of route. The participation of stakeholders in every stage of the planning from need identification to mode identification to corridor identification and finally route identification and impact assessment is rare. One such well documented and systematic procedure was implemented for the Highway 69 project in western Ontario for the Ontario Transportation Department in Canada (McCormick Rankin Corporation and Ecoplans Limited, 2003). Although a foresighted initiative, the analysis did not take into account stakeholder concerns and priorities in a spatial context and thus was not successful in its goals of achieving stakeholder satisfaction.

The method used in this research is founded upon the principles of meaningful stakeholder participation in the planning process by using spatial multi-criteria assessment thus improving upon contemporary techniques. Due to its procedural transparency, and its quantitative and qualitative outputs it "forces" all priorities, interests and concerns to be laid upon a common open platform for the consideration of, and weighting by, all. Thus route alternatives produced by this technique are transparent and are better positioned to be more sustainable. Although many proponents argue that involving stakeholders complicates planning, creates delays and increases costs they fail to realize that early stakeholder involvement is the best possible means to come up with relevant design criteria and consequently a better plan/project – better, in terms of societal, and possibly although not always, biophysical sustainability. In addition, such a project would have the needed societal legitimacy.

In the Netherlands in 2008, the Elverding committee published a report (Elverding, 2008) proposing structural improvements in the planning of infrastructure projects, which echo these very same principles. It is expected that the legislation will be passed in 2011, and the law implemented with retrospective effect from 2009 (Krol, 2009, Visser and Wortelboer- van Donselaar, 2010). The law aims at more uniform approach in stakeholder management, which would include a stakeholder manager who, from the stage of project proposal, would be responsible for:

1. Making an inventory of problems, requirement and design criteria
2. Identifying and adjusting solutions

3. Timely, open and elaborate communication of impacts to stakeholders
4. Organization of administrative consultation and agreements
5. Defining the overall scope of the project, as well the scopes of various stages.

Recognising and anticipating the importance of scale in planning, assessment and stakeholder engagement, this visionary law makes it incumbent upon the proponent to bring participation much more upstream in the planning process, to enable different rounds of public consultation and decision making. This law is a rare example of enlightened legislation which could enable an integrated assessment based planning, the likes of which is yet to be seen in most countries, but is worth emulating.

1.3.2 Improving upon current impact assessment practice

Alternatives identification in a SEA is designed to bring environmental and social considerations into the “upstream” stages of development planning—project identification and earlier—as well as the later stages of site selection, design and implementation. In the absence of such consideration, those first steps in the infrastructure development process are taken solely on the basis of technical feasibility, economics, and political preferences, and the EA for such a project tends to be directed to supporting or affirming a project proposal. At best, EA becomes a damage limitation exercise, with the benefits restricted to identification of mitigation measures. Whereas environmental and social analysis at an earlier stage might have revealed another cost-effective way of achieving the same project objectives at lower environmental or social cost (measured either by the severity of the impacts or the costs of measures to mitigate them). Furthermore, even if such an option were to be found in the project EA, it often cannot be implemented without disrupting project preparation in a manner that is so time-consuming and expensive, as to be impractical (World Bank and Environmentally Sustainable Development, 1996).

It is then logical that the two processes, of preliminary planning and impact assessment, be brought together and merged seamlessly; the criteria, scores and weights that would be used for impact assessment be used well upstream for formulating the route alignment itself. This reasoning and demand, although not new, could be materialized only recently due to the emergence of GIS as an analytical tool in spatial multi-criteria decision making.

A point to take particular note of is that, impact assessment has traditionally been oriented towards the consideration of negative impacts of the proposed intervention. The methodology proposed to be used in this is deliberately directed towards an integrated spatial assessment - the consideration of biophysical, social and economic, intended and unintended, negative and positive impacts along with their spatial contexts - as the main doctrine for highway planning, i.e. planning based on integrated spatial assessment. It is this principle, similar to that proposed by Partidario (2000) for SEA, along with transparency and stakeholder involvement that can play a key role in imparting credibility, salience and legitimacy to the planning of sustainable highways.

The proposed approach can address any level of the planning process from the policy level to the project level, through the plan and programme levels, as shown in Figure 1.8 and Figure 1.9. In fact, if it is used iteratively at all the levels it could ensure that the different scales of planning and environmental assessment are addressed, bringing it closer to sustainable development. The following chapter makes use of this conclusion to set out the research goals and objectives based on literature review.

1.4 The importance of issues of scale

Different fields use "large scale" and "small scale" to mean the opposite things, for example, cartographers referring to the mathematical size of the scale ratio, 1:24000 being 'larger' than 1:100000, while landscape ecologists, for example, would refer to the continental study as larger than a provincial study. However, notwithstanding these differences, the more fundamental issue of scale requires ensuring that the boundaries (extent), resolution (detail) and methods (of comparing) are defined objectively and that conclusion of the analysis does not depend on any arbitrary scale.

According to Quattrochi and Goodchild (1997) in the field of geography, 5 types of scales have been identified: Operational, Temporal, Cartographic, Observational, Measurement which represent only the technical aspects of scale in spatial analysis. It is found that technical anomalies such as Modifiable Areal Unit Problem (MAUP), Ecological fallacy (Openshaw, 1977, Openshaw, 1983, Openshaw, 1984) or spatial aggregation (Clark and Avery, 1976), may ensue if scales have not been defined and used objectively in spatial analysis. Such technical issues essentially come up in the empirical processes of a discipline. Systems analysis and computer models are very useful tools to improve our understanding of the dynamics behind certain observed processes, as well as to promote integration of different disciplinary perspectives, but there are many foundational issues that should be understood before their use.

From integrated assessment, Wilbanks et al. (2002) opine that although the scale continuum is a continuous function, there is a 'lumpiness' in human processes and therefore scales become discrete functions stepped at nodes such as community, village, provincial, national and global scales. They also state that in most cases, smaller scale mosaics are nested within larger-scale mosaics and that we can often think in terms of spatial hierarchies. However Gibson et al. (2000) compare definitions from Turner et al. (1990), Allen and Hoekstra (1990), Mayr (1982) to show that scales, whether they are inclusive or constitutive nested hierarchies, display different behavior or characteristics at different scales.

The prominent and widespread social implications of scale have led social scientists to coin a term called "politics of scale" (Lebel, 2006, Paasi, 2004, Swyngedouw, 1997). The Millennium Ecosystem Assessment, in the chapter aptly titled "The Politics of Scale", Lebel (2006), shows how through the strategic choice of scale one group of actors can alter the behavior of another group or influence the decision making process by subtly shaping the scales and contexts in which knowledge is organized or decisions are made. Cash et al. (2006) and Lebel and Garden (2005) state that "Scale represents a class of key choices, commitments and constraints that actors contest or are forced to accept." Karstens (2007, 2009) shows how problems can be magnified or shifted by political decisions taken to solve small scale problems without a full analysis. Stephen and Downing (2001) show how policies, geographically targeted at groups socio- economically vulnerable to natural disasters, can complicate the situation further if appropriate scales of assessment are not chosen.

A study done by the World Bank shows how the stakeholder priorities (expressed by weights seen in Figure 1.12) change at different scales and levels in a participatory planning exercise (Odoki et al., 2008). When one considers this understanding with the observations of Brenner (2001), Cash et al. (2006), Cox (1998b, 1998a), Lebel (2006), Meadowcroft (2002) and Swyngedouw (2000), it is possible to see how spatial planning done through participatory planning process, will show major differences and anomalies at different scales. It may also be seen that results derived from these shifting priorities may not necessarily be nested, and thus solutions need to be tailored to specific audiences and scales to impart the needed salience, legitimacy and credibility (Kooiman and Keshkamat, 2011). These are the most necessary attributes for information to cross over from research to policy (Cash et al., 2003).

Table 1 Weights and ranges for different types of benefits/costs, social benefits/costs, and different social costs and benefits

Benefits/costs Category	Levels		
	Micro (Community)	Meso (District)	Macro (National)
	Mean (Range)	Mean (Range)	Mean (Range)
Type of benefits/costs			
Economic	0.22 (0.05-0.64)	0.33 (0.04-0.78)	0.47 (0.07-0.78)
Social	0.65 (0.26-0.81)	0.51 (0.05-0.79)	0.26 (0.07-0.69)
Environmental	0.14 (0.05-0.21)	0.16 (0.05-0.49)	0.27 (0.08-0.73)
Social benefits/costs			
Social Costs	0.17 (0.16-0.2)	0.26 (0.1-0.90)	0.71 (0.5-0.88)
Benefits	0.83 (0.8-0.84)	0.74 (0.1-0.90)	0.29 (0.13-0.50)
Different Social Benefits			
1. Increased access to health facilities	0.43 (0.14-0.70)	0.45 (0.04-0.69)	0.27 (0.26-0.28)
2. Increased access to clean water sources	0.30 (0.04-0.70)	0.32 (0.06-0.70)	-
3. Increased access to educational institutions	0.23 (0.11-0.48)	0.29 (0.11-0.65)	-
4. Access to information, new knowledge, and modernity	0.05 (0.04-0.07)	-	0.47 (0.33-0.75)
5. Access to markets	-	0.15 (0.08-0.32)	0.27 (0.13-0.33)
Different Social Costs			
1. Increased road accidents	0.52 (0.13-0.68)	0.41 (0.17-0.72)	0.38 (0.06-0.78)
2. Increased insecurity & crime	0.32 (0.03-0.72)	0.13 (0.03-0.53)	-
3.Increased incidences of diseases	0.09 (0.07-0.1)	0.37 (0.07-0.65)	-
4. Negative cultural influence	0.04 (0.04-0.04)	-	-
5. Loss of land and property	-	0.1 (0.03-0.36)	0.18 (0.04-0.74)
6. Mud and dust pollution	0.06 (0.06-0.06)	0.16 (0.04-0.40)	-
7. Social consequences of environmental degradation	-	-	0.29 (0.19-0.75)
8. Resettlement problems	-	-	0.18 (0.08-0.50)

Figure 1.12: Stakeholder priorities at different levels (Source: Odoki, 2008)

Scale also makes an enormous difference in the generation of alternatives. For example, Keshkamat et al. (2009) demonstrated a new GIS-based participatory method for route planning of the Via Baltica expressway, a major European highway. They derived the “optimal alignments” as the path of least impedance across an impedance-map obtained by a spatial multi-criteria assessment derived from stakeholder criteria and preferences. They have shown how different routes can be obtained for different visions – economic, social, ecological, and balanced; however, they do not take into account that the proposed route alignment would change if the spatial analyses were done at different geographical or temporal scales – both at different resolution (i.e. pixel-size) and at different levels. Furthermore, stakeholders as well as stakeholder priorities and concerns can be different at different levels. A spatial sensitivity analysis, such as that illustrated by Berry (1996), shows that optimal route alignments may change radically - even up to 97% of the total length - if the weights are changed by as little as 12-15%. Hence even in the field of planning and assessment practice, this brings to light an issue of serious consequence – the sustainability, salience and legitimacy of the proposed project are scale dependent.

Marceau (1999) states that the problem of scale, or the scale issue, can be simply expressed "in terms of two complementary and fundamental questions: what is the appropriate spatial scale for the study of a particular geographical phenomenon?, and 2) how can we adequately transfer information from one spatial scale to another?". Although in recent years much work had gone into understanding the concepts of scale (Atkinson and Tate, 2000, Atkinson and Foody, 2002, Goodchild and Quattrochi, 1997, Rotmans and Rothman, 2003), no profound pivotal theories were formulated as in many other disciplines. The most common practice, amongst the few who attempt to address the issue of scale in their scientific research, is to use some feature as a "defining context", a limit so to speak, at which the system boundary of the study will be set-up. For example, river hydrology based research often derives its extent from the water divide, just as urban studies draw their boundaries at municipality limits. However, although it is not always correct to do so, even if the extent is derived so easily, the resolution of the study should still be given much consideration. Often the data availability drives this decision in most studies and planning processes. From a stakeholder's perspective this could be an unfortunate consideration because in most cases, the choice of extent and detail will decide the stakeholders who are likely to be affected, as well as the extent of issues that will be associated within the system boundaries. Therefore in order to model the system as realistically as possible the choice of scale should also be driven by a thorough stakeholder analysis rather than merely through criteria such as data availability.

However, in actual practice such considerations are rarely taken into consideration. Scale selection is done at the Terms of Reference (ToR) stage of a project by the proponents in consultation with managerial experts. In aided development projects for example, scales are usually set by the donor. In non-development aided projects usually by the appointed consultants/experts at the behest of the proponent (Cash et al., 2006, Lebel, 2006, Wilbanks, 2008). Data constraints are often the governing factor in this selection (Gontier, 2007, João, 2000), but in many cases the electoral interests of the ruling party (Romein et al., 2003) play a role. Choices of boundaries and levels are critical because they are used to decide who is a stakeholder. Scale-dependent interests are likely to be articulated only if they are represented. Tightly set boundaries can ensure that off-site, higher-level interests are only weakly represented, to the advantage of local interests, and vice versa. Table 1.1 in which Karstens (2009) enumerates some typical strategic considerations of powerful stakeholders or proponents in making scale choices.

Interest of an actor	Strategy	Actors may be in favour of a......
Putting on agenda a certain problem he/ she considers important	Make scale choices in such a way that they contribute to getting the issue central on the agenda Fade out other problems that are considered less important (or unsolvable) by the selection of a smaller spatial and/or temporal scale and a high level of aggregation	Spatial and temporal scales on which the problem he/she wants to address is dominant Spatial and temporal scales on which the other problems fade into the background
Rationalising in favour of a certain solution	Let positive effects look more positive and let negative effects look less negative	Spatial and temporal scales that place this solution prominently on the agenda and ignore other options High level of aggregation to underplay negative information in the details Spatial or temporal scales on which negative consequences are not immediately visible: • (Large) scale if it is possible to average out the effects of measures • Limited scale if the solution has negative effects on a larger scale
Shelving to delay the study	Involve everything and everyone	• Scale on which many stakeholders are involved • Large spatial and temporal scale in combination with low level of aggregation
Hurrying the study: because urgent interests are at stake	Take what is out there and do it quick	• Limited time scale for information support • Small spatial boundaries and a high level of aggregation, • Select a scale on which information and models are readily available
Shirking by shifting the problem to another actor	Shift problem to a larger scale or into the future	• Select a scale on which the actors involved have no authority • Show the difficulty of finding solutions on this specific scale

Table 1.1: Strategic considerations in making scale choices (Source: (Karstens, 2009))

Perhaps recognizing the need for solutions that transcend the politics of scale, many researchers have laid claim to the multiscalarity of their methods, models or analysis (for example Ewert et al. (2006), Janssen et al. (2009), Jolly et al. (2005), Parker et al. (2002)). Critical appraisal will reveal that although most of these methods can be used at different scales, they can only be used at each scale - one at a time and not in a trans-scalar manner as defined by Whittaker (1999) or Bannini (2003). Thus, the need to identify and state the scale at which the study is conducted at the time still remains, and if there is a need to conduct the study at different scales, they should be compartmentalized into several such sub-studies, the “context” (Janssen et al., 2009) of each sub-study well and clearly defined. In an understanding of this situation, the Millennium Ecosystem Assessment defines multi-scale assessment as a process that incorporates at least two complete nested and interacting assessments, each with a distinct user group, problem definition and expert group. However, Romein et al. (2003) with evidence from the Randstad–Flemish Diamond megacorridor show the widening mismatch in multi-level governance of the nation-state between the planning scales of a sovereign state as a definite territorial unit, and the realities of modern economic systems which reach out to and from global markets. For a solution to be trans-scalar, the problem would be to find a common ground in which all stakeholders feel a sense of belonging both at the local and the global scale (Tomlinson and Fry, 2000) - a very complex problem if all stakeholders can be identified (Figure 1.13).

This concept of the 'Glocal identity' (Swyngedouw, 1992, Swyngedouw, 1997, Swyngedouw, 2004) has formed a foundation stone of the United Nations Rio Conference on Environment and Development (1992), and has been codified in many official documents such as the Millennium Development Declaration, the report of the Commission on Global Governance etc., but has found resonance with researchers dealing with scale in planning and governance only recently (for example Governa and Salone (2004), Manson (2008), Mamadouh et al. (2004), van der Wusten and Mamadouh (2008), Majoor and Salet (2008)). However although such a concept may ring true with the ideals of human "global identity" and seem intrinsic to the principles of sustainable development, the challenge lies in reconciling it with a fundamental concept of geography that states that entities in close proximity often share more similarities and commonalities than entities which are far apart. (Tobler, 1970).

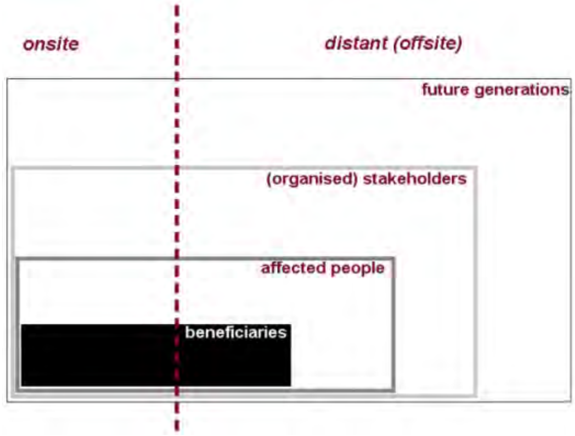

Figure 1.13: Stakeholder identification and categorization (Source: Slootweg, 2010)

Although like Hay et al. (1997), Kent and Schneider (1994), Allen and Hoekstra (1990), we find that extent (width) and resolution (grain or detail) are the two key lenses in the "formulation" and inquiry of scale, we also find from literature that the research and discussion on scale has been steeped in the individuality of the discipline that the researcher hails from. Thus, although great depth has been achieved in individual disciplines, a comprehensive understanding of the complex problem of scale has eluded the scientific community in general. We liken it to the situation in Figure 1.14 below (Himmelfarb et al., 2002).

Figure 1.14: Understanding a large complex multi-disciplinary issue (Adapted from: (Himmelfarb et al., 2002)).

Rothman (2003) opines that there is a growing need for interdisciplinary approaches to scaling issues by holistically combining insights from both the natural and social sciences in order to pave a way for a more common understanding of the role of scale in many current societal problems. There needs to be a greater crossing of boundaries between disciplines; for this there is a need for a framework that can bring together the philosophical, theoretical and practical schools of thought from various disciplines. Such a framework should incorporate the concept of tiering in governance, decision making, and focus within reality, but also societal, institutional, and even in mindsets of stakeholders. At the same time it should be able to deal with choices of scale relating to the spatial and temporal characteristics of data and models, while always keeping as core theme the issues to be planned and assessed. Such a framework will be presented in Chapter 4. The thesis itself is structured based on a tiering approach to issues as seen in SEA practice (Section 3.2), but will refer to scales of data and models at the level of each case study.

2 The research

The research niche, objectives and thesis structure.

Highlights

This research aims to aid the planning process with assessment-based strategic thinking so that the sustainability of highway developments can be substantially improved.

It will draw upon the principles of SEA which similarly espouse strategic thinking in assessment and decision making – transparency, good information and robust public participation.

Research objectives to address these issues are identified and thesis structure formulated according to these principles.

The thesis' SEA-like tiered structure is intended to demonstrate how GIS and remote sensing can help bring transparency and public participation at each tier in the planning process without demanding a considerable increase in institutional capabilities.

2.1 Introduction

The goal of this research is to explore the components of sustainability (bio-physical, social, economic) for good practice, multi-scale decision making of highway infrastructure development projects, by augmenting positive impacts and reducing negative impacts, using the 3 main precepts of SEA:

- Transparency,
- Good implementation, and
- Public participation.

SEA is about knowledge through good quality information based on:

1. Credibility: information has to be scientifically valid
2. Salience: information has to formatted for the right audience
3. Legitimacy: stakeholder involvement during the process and recognition by stakeholders of their interests in the information outputs provides legitimacy

These principles of good quality information for decision making, which are key to the understanding and development of this research, are introduced below.

1. Credible information: Paucity of data has often been expressed as a major justification for non-application of spatial methods in highway alignment planning. Information such as traffic density, travel demand, existing networks, boundaries of natural and semi-natural areas are very difficult and/or expensive to obtain as they require extensive field-data collection. Then also, the accuracy of the collected data is uncertain. Satellite remote sensing (RS) can provide a quick and efficient solution to many of these data requirements. However, many of these information requirements cannot be obtained directly from RS imagery but have a definite correlation to some component characteristics of the imagery. Identifying these correlations can be the valid answer to many questions and requirements posed by highway planners. Especially at higher planning levels (and the SEA of this planning) where geographic scale may be large and uncertainty is high. The combination with limited time and financial means makes the use of RS information the logical choice for providing good quality

information (credibility). Objective 2 and its research questions refer to this precept.

2. Stakeholder involvement (legitimacy): The inclusion of stakeholder concerns and priorities as criteria in the modeling process provides a means to have the interests of stakeholders taken into account (Objective 3). A framework which can provide a means to include experts' knowledge and stakeholder values in perspective is needed.

3. Transparent decision-making (salience): the information resulting from the process provides information for decision-making; the consequences of the decisions have to be clear for everybody (decision makers as well as stakeholders). This puts a special responsibility on the one providing the information. GIS-based outputs – the mainstay of this approach – that are both quantitative and visually explicit by nature allow decision makers to take verifiable and accountable decisions. When combined with transparency in each step of the methodology, this approach endows salience to the decision-making process. (Objective 4).

4. The institutional perspective (Objective 5): the process to be implemented must bring about significant and perceivably more meaningful outputs within institutional means and capabilities.

However, in order to address the above explained principles in rational decision-making in a spatially explicit context, the effects of scale need to be fundamentally taken into account beforehand (Berry, 1996, Berry, 2005, Odoki et al., 2008). Sustainability is a scale dependent concept, because boundary definition, level of detail, effective time period of the planned infrastructure, stakeholder involvement, data needs, appropriate model choice etc. are all decisions derived from scale choice (Bell and Morse, 2008). In recent years, extensive research has been conducted on scale issues and impacts in specific disciplines and particularly with respect to geographic (observational) and measurement (resolution) scales, but with the emergence of digital spatial information and concepts such as globalisation and glocalisation increasingly taking centre stage in research, the need to study scale as a generic, trans-disciplinary parameter is increasingly felt (Goodchild, 2011). Hence this forms Objective 1 of this research.

In traditional impact assessment, stakeholders are assumed to be real people on the ground, but at SEA level more often than not, representative stakeholders such as local authorities, NGOs, etc. will be involved. In transnational highways such as the Asian Highway, stakeholders are also national governments, international financing bodies, trade organization etc. Identifying stakeholders likely to be affected by the proposed intervention and how the concerns and priorities of various “upper levels” of stakeholders can be knitted into the concerns and priorities of “foundation level” stakeholders also forms an interesting investigation of scale and legitimacy.

To an impact assessment professional or a decision maker in highway planning, the ambiguity associated with generalisation due to scale can make a vital difference for arriving at the correct decision, particularly when information is being integrated from a number of disciplines and sources. For example, in the planning of a geographically large-scale investment such as an international highway using the proposed method, it would be necessary to understand, what is the effect of scale, in providing the decision maker with credible, salient and legitimate information.

Although many of these different scales appear to interact and inter-relate to each other, some do in fact compete (or even conflict) with each other, causing problems such as the modifiable area unit problem (MAUP) or the ecological fallacy problem or the problem of inferring spatial processes across scale. The Millennium Ecosystem Assessment (MEA) considers scale to be a very important issue which influences both the problem definition as well as the assessment results. The MEA therefore strongly recommends a multi-scale approach in the integrated assessment of a proposed intervention (Berkes et al., 2006) and indeed, a multi-scale approach which can achieve an optimal balance between these different scales is a key necessity to impart transparency and efficacy to the decision making process.

2.2 The research niche

With this background in mind, the research niche for this study is formulated as: **The formulation and assessment of sustainability-led highway alignment alternatives by taking into account stakeholder concerns and priorities in a transdisciplinary, multi-scale context, enabled by spatial information and analysis.**

2.3 Research objectives

If the reasoning presented so far is scrutinized it becomes possible to define and structure the individual goals of this research as below.

2.3.1 General/overall objective

The overall overarching goal of this research is to use geo-information tools and techniques as a vehicle for developing more sustainable corridor alternatives, based on a transparent set of criteria, without being hindered by proponent biases.

2.3.2 Specific objectives

Objective 1: To develop a framework on scale which can be used to scientifically understand, explain, negotiate and select scales in a transdisciplinary context.

Objective 2: To develop methods for providing appropriate information to decision making, that is information conforming to the three principles of credibility, salience and legitimacy. Towards this objective, the following two hypotheses can be formulated:

- Remote sensing imagery can be used to significantly compensate for paucity of spatial data, a key necessity for good quality highway planning.
- Natural areas vulnerable to ecosystem fragmentation can be identified and graded by combining established ecological indicators with remote sensing and GIS.

Objective 3: To understand the highway planning process and contribute to meaningful utilisation of stakeholder input in highway planning processes at different spatial scales or planning tiers, without losing practicality.

Objective 4: To develop strategies and methods to aid transparent decision making in infrastructure planning through alternatives generated by incorporating stakeholder participation and good quality information. The following hypotheses are formulated to fulfill this objective:

- Ecological, social and economic rationalities can be combined to common advantage by use of spatial multi-criteria decision making methods.
- Methods that provide quantitative and spatially explicit results can aid and enhance transparent decision making and increase utility of the intervention.
- Spatial decision support tools enable more environmentally friendly planning.

Objective 5: To assess the dimensions of highway planning as an institutional management tool in development. The aims are:

- To develop and demonstrate a technique for planning a highway corridor that can incorporate policy level goals in the route alignment process, thus allowing the highway to be used as a focused instrument in development.
- To show that spatial decision support tools can bring added value to the highway corridor planning process without significantly increasing the institutional capabilities needed.

2.4 Thesis structure

Chapter 1 set stage for this research by introducing the research arena, identifying lacunae, raising issues that need addressing and indicating practices which can be improved upon. This chapter introduces the research and the path intended to conduct it. Chapter 4 will propose a boundary object using which issues of scale choices may be better understood, stated and negotiated in transdisciplinary contexts.

Then, through three carefully selected real-life in-progress projects as case-studies the use of an impact-based route planning methodology at multiple scale levels using the boundary framework on scale, will be demonstrated. As mentioned before this research draws heavily upon the principles used in a transport SEA, and makes effort to improve the SEA process. Figure 2.1 shows the tiered structure of this thesis and Figure 2.2 shows the overview of chapters.

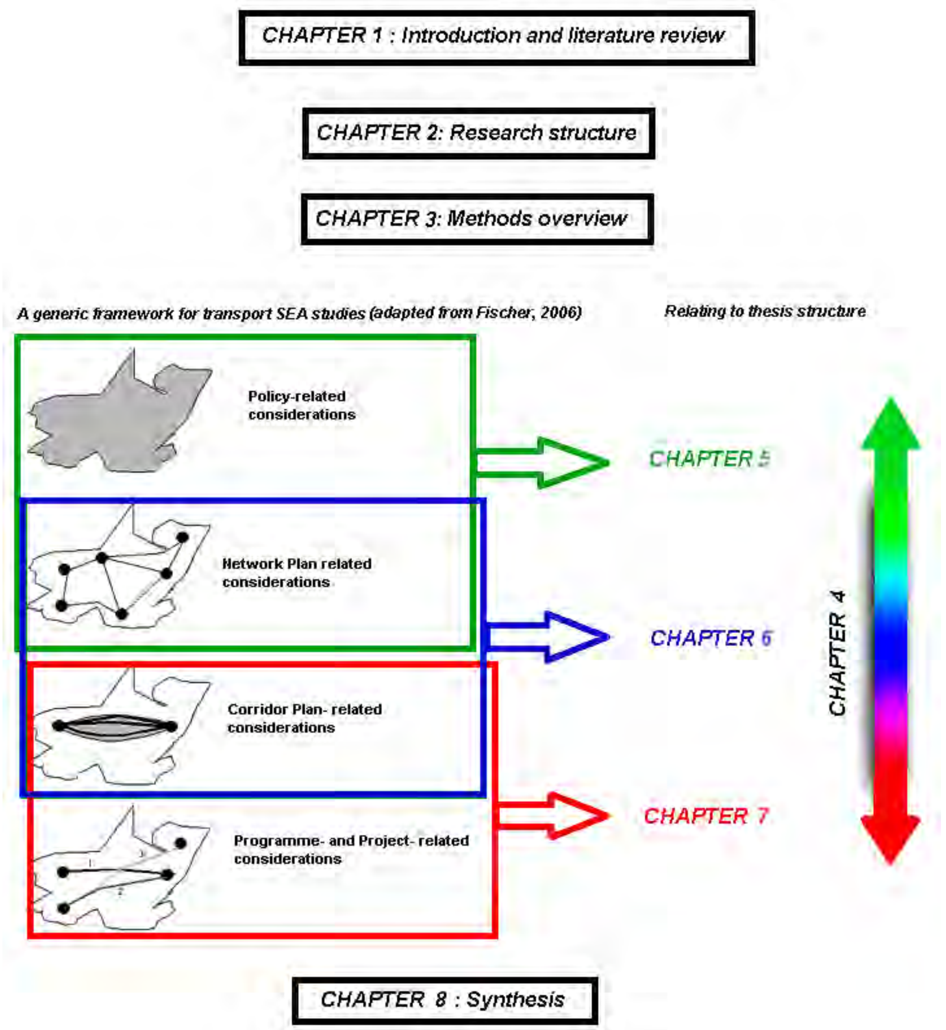

Figure 2.1: Thesis' structural context.

In Chapter 5 the case study of a very large-scale trans-national highway, the Millennium Road of Mongolia, is taken up. At an enormous 3000 km length, this highway is part of an even larger program – The development of the Asian Highway network. The routing of the highway presents an interesting plan structuring challenge. Being an international highway, it has stakeholders at the international level, but also national level and local level. Questions such as: “Can the highway be designed to address broad national and international goals, without compromising regional and local priorities?” and, “What are the model and data structures used in such a multi-scalar planning process?” will be addressed.

Chapter 6 is the case-study of the Via Baltica Expressway in north-eastern Poland. This highway, considered a priority component of the transcontinental Trans-European Transport (TEN-T) network ran into stakeholder dissatisfaction on a regional 350km portion due to its non-transparent planning processes that had potential to cause severe ecological damage to some of Europe’s oldest and best protected natural areas. “Can regional scale ambitions be better (more efficiently) addressed within the same context as larger national goals?” is a moot question addressed in the chapter.

Chapter 7 takes up the issue of dirt roads in Mongolia. The lack of proper all-weather roads is spurring the formation of dirt-road corridors in this vast country with a sparse population. These dirt roads, some of them several kilometres wide pose serious and far-reaching consequence in terms of land-degradation and eventually desertification. Using satellite imagery we investigate and estimate the impact of these dirt-road corridors on the main national (and regional) vehicular arteries. We then use this information along with other spatial information to generate an assessment ‘surface’ which can be used to locate hotspots and alleviate the problem, by means of fine-scale low-cost/cost-effective interventions. The outcomes of this chapter would also enable the prioritisation of projects within the programmes.

Chapter 8 concludes this dissertation by relating the lessons obtained from the case-studies to the research objectives, and the boundary object of scale, in order to synergize both theory and practice.

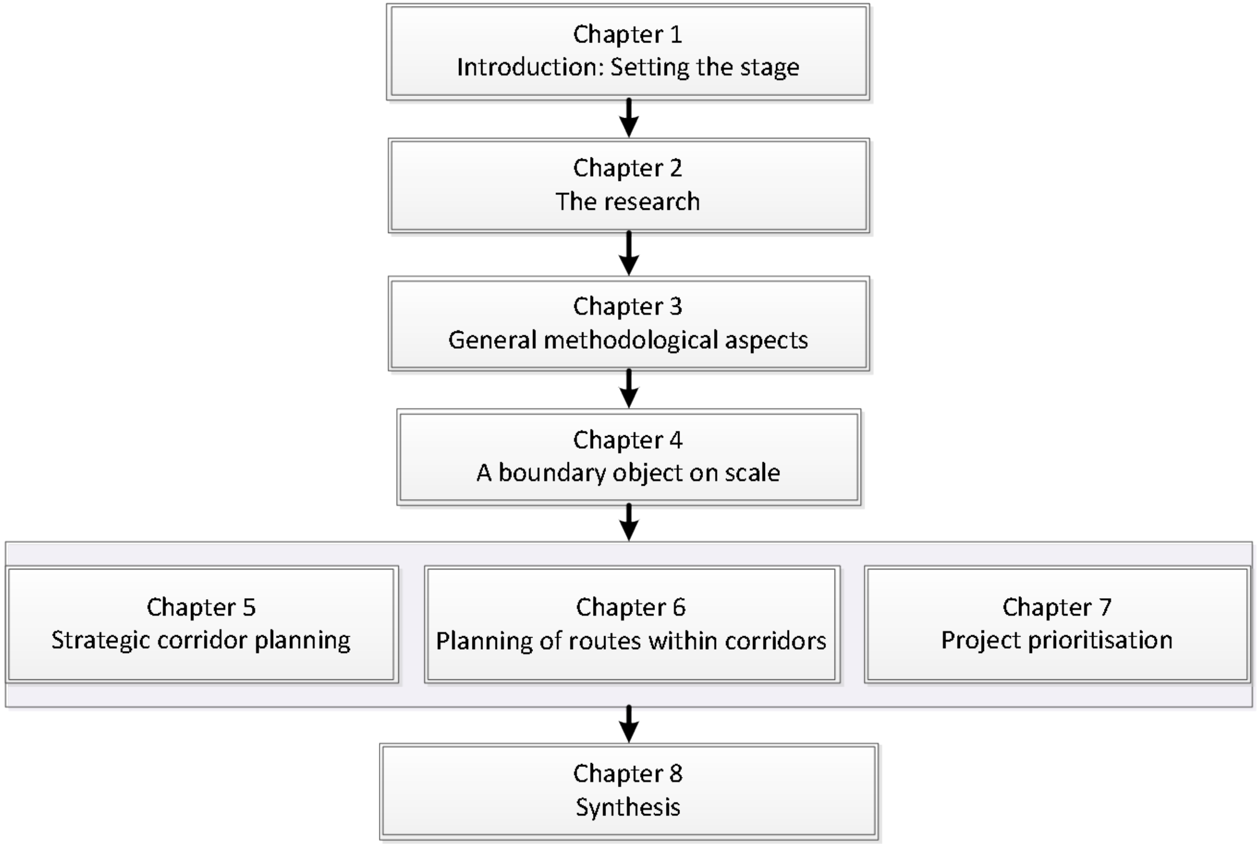

Figure 2.2: Overview of the chapters in this dissertation.

3 Key methodological aspects

Overview of key methodological aspects used in this research.

Highlights

This chapter provides an overview sketch of the three main methodological aspects in this thesis. A distinction needs to be drawn between the concepts of level (tiers) and scales.

Tiering of planning and assessment plays a key role in this research. Four tiers – Policy, Plans, Programmes and Projects are proposed.

At the level of planning within each of these tiers, scale choices need to be made in terms of issues to be addressed, stakeholders to be included, models to be used and data required.

Spatial multi-criteria assessment is a technique that will be used often in this research. In conjunction with other techniques, it offers the ability to objectively and spatially take into account the concerns, priorities and opinions of diverse stakeholder groups in a transparent manner.

3.1 Introduction

This chapter gives a concise introduction to three main umbrella methodological concepts that will be iteratively used in this dissertation, i.e. tiered planning, scale and spatial multi-criteria analysis. At first, the distinction between the concepts of level (tiers) and scales needs to be drawn.

According to Maurer (2002), a level is a theoretical construct used to induce a conceptual order or hierarchy in the understanding of complex systems, whereas a scale is an empirical construct used to organise data collected by scientists studying complex systems. Because real-life issues in highway planning are regulated by input and governance from multiple scales, it is usually not likely that any one single modelling technique can capture every important spatial, temporal, legal aspect or set of stakeholder opinions of the planning or assessment.

King (1997) advocates that levels should be extracted from data rather than assumed to exist a priori, a line of opinion which draws its strength from inductionist views in ecology. Given however that usually there isn't a single universal model that can explain (and plan or assess) an entire gamut of situations, Pickett et al. (1999) and Maurer (1999) rightly find and argue that the inductionist view limits progress in science – all issues will remain too complex to be understood, and patterns too intricate to be seen. They propound the deductionst view i.e. that levels be defined a priori, in a manner that can be used to explain and model (and plan or assess) reality. Data collected at appropriate scales can then be used in explanatory models at each level.

Because, we feel that solutions to real life problems need to be issue-driven, rather than data-driven, as is often seen in contemporary practice, this research takes the line of Conroy and Moore (2002) and Dobson et al. (1999), who suggested that, in a decision making context, modelling, explanation and verification/implementation should be a hierarchical iterative procedure, where what is learnt at one iteration forms and informs the choices of models and scale choices at the next (higher or lower) level. This research then allies itself with the deductionist view of science. In line with this, the following sections will present an overview of tiering in planning of highway corridors and an overview of appropriate scale choice within each planning tier.

3.2 Tiered assessment and planning

In order to realise the research objectives set out in Section 2.3, a tiered thesis structure will be developed as mentioned in Section 2.4. Four tiers – Policy, Plans, Programmes and Projects are proposed and tabulated (Table 3.1), showing the focus, tasks and goals at each level. Once the issues at stake can be identified, stakeholders can also be accounted for with greater surety and appropriate stakeholder engagement techniques can be formulated. As shown in Figure 2.1, each chapter will consist of a combination of levels of the tiered structure.

Seen in light of Figure 1.9, Table 3.1 shows hypothetically how at a high (or early) level, the tasks, focus and goals are broad, coarse and often somewhat abstract by nature. They become finer and more utilitarian at lower tiers which occur closer to project implementation. The stakeholders also change from large representative national or international bodies, to local levels where individuals who will be personally affected may play a role.

Although it will not be made explicit in this research, there is also a process of diagonal tiering at play at lower levels, and if feedback is built-in, at upper levels as well. That is why decisions taken by policies related to other aspects (such as education, for example) can also be accounted for in transportation plans. Tiered planning thus enables confluence of several goals in the nesting of alternatives. Reflected in Chapter 5 which takes into account Millennium Development Goals from different sectors into account for highway corridor planning, the presence of such diagonal tiering thought will also be seen manifested in Table 3.1.

Systematic decision-making tier	Focus	Tasks	Goals	Potential Stakeholders (typical)
Vision and policy	Addressing all policy options that might lead to meeting stated policy goals and objectives.	Analysis of the current situation enumerating existing economic, social and environmental objectives and targets and adaptations to transport. Identifying different development scenarios (e.g. economic and spatial) Identifying different policy options that may lead to objectives and targets Evaluating options in the light of scenarios, Indicating trade-offs for achieving objectives and targets, Policy assessment, monitoring and adjustments as per actual responses.	<u>International goals.</u> Improve international mobility and market access to: Ports International highways Production centres International Tourism Employment generation (direct & indirect)	1. National governments 2. Development agencies and development banks. 3. Sectoral organisations 4. Distant stakeholders
			<u>National goals</u> Improve access to • Income generation • Basic health care • Basic primary education	National, Provincial and local governments. Local producers and service providers (industries and farmers) Local citizens Conservation organisations concerned with policies

			Improve national mobility Ensure environmental sustainability	
			<u>Long-term goals</u> Reducing rural-to-urban migration Increasing capacity to withstand/ respond to: • Natural disasters • Market fluctuations • Adverse effects of climate change	National, Provincial and local governments. Farmers, herdsmen and other local citizens.
Plans	<u>Network plans</u> • National or regional infrastructure development options leading to specific transport development choices	<u>Network assessment</u>; • Analysis of current situation identifying – intermodal – development options according to needs identified in policies • assessing impacts on different options to achieve objectives and targets. • indication of possible trade-offs • feedback to policies	Rail corridors Highway corridors Ecological corridors Terminals: • Intermodal trans-	National and provincial governments Transport companies and users Conservation organisations concerned with national and regional projects

		• monitoring actual developments	shipment • Airports • Border posts	
	Corridor plans Identification and spatial locations of corridors between nodes specified in network planning	Corridor assessment • Analysis of current situation • Identification of potential impacts (advantages and disadvantages) within corridor • Identification of stakeholders, visions, concerns and priorities	• avoidance of negative impacts to greatest extent possible • development of alternatives based on visions from upper tiers taking into account biophysical, social, economic, technical and technological factors • feedback to policies and networks	Provincial and local governments Funding agencies and banks Conservation organisations concerned with landscape fragmentation and regional projects Producers (prospective and existing) and Users
Programmes	Identify priority projects: • in each network sector, • in each corridor	Programme assessment • Analysis using multi-criteria analysis, cost benefit analysis, etc. •Monitoring actual developments and regularly adjusting them	• concrete impact assessment translated into factors and objectives • avoidance of negative impacts to greatest extent possible • development of alternatives based on visions from upper tiers taking into account biophysical, social, economic, technical and technological factors	Provincial and local governments Funding agencies and banks Conservation bodies concerned with specific species or zones, regional projects

			• feedback to policies and plans	Local industries (prospective and existing), Land-losers, future users
Projects	Project design	<u>Project EIA</u>	Optimise project design in terms of programme objectives and targets.	Provincial and local governments and politicians
	Identify priority sections	Mitigate and compensate impacts that cannot be avoided.	Identify focal species, locate and design mitigation measures	Proponents, construction companies, engineering & project consultants
	Minimise negative construction impacts. Procedural optimisation: expedite execution, maximise financial benefits, technical design, technology and contract management.	Manage local stakeholders	Land acquisition, identification and conciliation of key local stakeholders' concerns	Conservation forums concerned with local ecological losses
		Monitor actual developments.	Monitor impacts : baseline, during construction and post construction	Funding agencies and banks

Table 3.1: Highway planning by tiering.

3.3 Applying scale to tiering

The prefixing of terms such as 'large-scale', 'small-scale', 'micro-scale' to a subject is as common in development initiatives, infrastructure project financing, impact assessment and spatial planning, as it is in the more empirical and philosophical fields. In colloquial vocabulary, it is often used quite subjectively, based on the author's (or speaker's) own immediate perceptions or experience. Such colloquial use does not necessarily reflect or affect an actual geographical extent and therefore may not influence the implementation or outcomes of a decision or process. However, the choice of scale in actual implementation processes carries much weight and may well affect the sustainability of the project – environmentally, socially, economically and politically. Thus it should not be a decision taken lightly. One FAO publication provides a rare and simple instruction for scale-choice - the right scale of a study is that which will fit on one map sheet (FAO, 2011). However, most researchers and practitioners can only wish it was indeed as easy. The advance of GIS technologies, management and productivity tools for spatial information, which has enabled us to easily present different aspects of information, often by representing the same data at different map scales, has made the problem more complex.

In science, scale is often described as one of the most overworked and yet, continuingly ambiguous terms. It may be used to refer to the magnitude of a study (i.e. its extent), the degree of detail of the study (i.e. its resolution) or a means of comparing the objects in a study in a meaningful way. It has been used in the context of space, time, individuals, hierarchy, perceptions, turnover, levels of governance and much more. Every discipline claims it as its own, as an intrinsic component of scientific inquiry in the discipline, with its own so-called 'universal definition' of it, thus making its use in a multi-disciplinary context, such as spatial planning, all the more difficult. Indeed it is as difficult to identify a completely 'scale-less' discipline, as it is to identify a common trans-disciplinary definition of the term. Our world is living proof of this conundrum; the closer we look, the more detail we see, but we also see more detail, albeit different detail, when we look wider.

One of the issues is simply of linguistic definition. Scale definitions have typically been derived from landscape ecologists and geographers. In mainstream science although mentions have been made of attempts to explain scale choices, multi-scalarity and even trans-scalarity, most studies preferred to just define the scale of the study and zoom in to it quickly. In recent years however, complex issues operating at multiple scales such as climate change, globalization and ground water depletion, international water treaties etc., have forced researchers in almost all fields – economics, social sciences, philosophy, ontologies etc. to take an urgent relook and make more strenuous efforts into the understanding of scale. Recognizing the complexity of the issue, Joao (2007) and Partidario (2007) called for a research agenda to better understand scale issues in assessment; the STS school at Oxford University (2009) call for a school of 'scalography' thought "*to turn the 'problem of scale' into an object of productive inquiry*". The Millennium Ecosystem Assessment (Berkes et al., 2006) dedicated a separate volume to the issue of scale to "*illustrate the multiple dimensions of the challenges inherent in bridging scales and knowledge systems*", while Goodchild et al. (1997) even called for a "*separate science of scale*". This research seeks to integrate contemporary scale-related research from several disciplines in order to:

- Identify commonalities across often very different disciplines and schools of scale inquiry;
- Use these commonalities as a device to advance the understanding of scale issues by infusing ideas and techniques from one discipline to another;
- Create a framework that can be applied across the theoretical, applied and philosophical aspects of various disciplines, whether they are spatial, temporal, spatio-temporal or hierarchical.

Although they do not provide a ready checklist solution or standardized procedure, such frameworks should be seen as 'boundary objects'. Star & Griesemer (1989) define a boundary object as framework that is plastic enough to act as a mediator between different disciplines, facts, knowledge, interest groups and individuals, and yet is robust enough to maintain a common identity across them. Harvey & Chrisman (1998) state that "*Boundary objects moderate differences and establish a shared understanding that not only enables (partial) agreement across ontological and epistemological boundaries, but also leads to the creation of 'things' with increased validity to a much larger portion of society."* The proposed boundary object is therefore a means to find a reasonable and feasible way to understand, communicate, negotiate and decide on suitable choice of scale in applied, theoretical and philosophical spheres of science.

Slootweg & Mollinga (2009) state that, *"in situations where interdisciplinarity or transdisciplinarity are required for effective analysis and decision making, as is the case in most planning and environmental assessment situations, the problem of boundary crossing presents itself. Boundaries have to be crossed between three main domains: research (credibility), policy (salience) and society (legitimacy)"*.

In the following chapter the 'problem of scale' as a boundary concept will be presented and developed into a vehicle for communication between different disciplines by means of a framework which can act as a boundary object in an transdisciplinary scale-less working context like that specified by Star (2010).

3.4 Spatial multi-criteria analysis

A common technique that will be used in this thesis is spatial multi-criteria analysis (SMCA), or spatial multi-criteria evaluation (SMCE) or spatial multi-criteria assessment (SMCA), as it is sometimes called depending upon the purpose for which it is used. It is amenable for analysis and development of alternatives at any level. Although in each chapter, it will be used in a different setting by pairing it with another appropriate analytical technique as per the specific requirements of the case-study and planning tier, SMCA which is a very versatile technique, enables this research to objectively and spatially take into account the concerns, priorities and opinions of diverse stakeholder groups in a transparent manner.

SMCA is a GIS technique belonging to the family of techniques classified as Multi-criteria analysis (MCA), which are used to arrive at a decision or solve a problem by weighing different factors in combination. In daily life we all weigh several criteria implicitly before we take a decision and we are often comfortable with the consequences of such semi-intuitive decisions. On the other hand, when stakes are high, it is important to properly structure the problem, explicitly enumerate the various criteria and evaluate a decision based on the weights of the decisions. For example, in making a decision of whether or not to build a landfill site or highway, there are not only very complex issues involving multiple criteria, but there are also multiple stakeholders who will be deeply affected by the consequences. Structuring complex problems and considering multiple criteria explicitly, leads to more informed and often better decisions (Bonte et al., 1998, Janssen, 1992).

There have been important advances in this field since the start of the MCA techniques in the early 1960s. One of the biggest advances was that with the advent of GIS, MCA took on the spatial mantle, thus being able to identify not only whether or not to build the afore-mentioned landfill site, but also where to locate it, if it is to be built, based on the same criteria that would have been used in the MCA (Jankowski, 1995, Malczewski, 1996).

SMCA has been used in addressing a variety of issues ranging from the siting of landfills (for example, Chang (2008), Higgs (2006), Leao (2004), Sharifi (2004)), power plants (for example, Georgopoulou (1997)) or housing conurbations (for example, Al-Shalabi (2006), Natividade-Jesus (2007) to evaluating locational suitability such as for agricultural crops (For example, Farhadi Bansouleh (2009), Thornton (2001)) or forest function (for example Vogt (2009)), habitat suitability (for example Store (2001), Villa (2002)) or for assessing the vulnerability of a location to natural calamities, such as floods and earthquakes or landslide assessment (for example Abella (2007, 2008), Barredo (2000)). Essentially however, SMCA is used in three broad classes of problems:

- Suitability analysis,
- Vulnerability analysis, and
- Cumulative effect evaluation.

Although SMCA has usually been used mainly in problems involving areal characteristics, there are increasing instances of it being used in linear applications as well. In this research they will be adapted for the linear applications associated with highways. Nijkamp (1990) and Vreeker (2002) state that multicriteria evaluation offers the perhaps best way to incorporate varied criteria and different perspectives in a manner that can support transport decisions based on alternatives derived through stakeholder consensus.

In a SMCA, criteria are usually classified into costs, benefits or constraints, based on the type of impact. A spatial benefit is defined as a criterion that contributes positively to the output; the higher the value, the better it is. A spatial cost is defined as a criterion that contributes negatively to the output; the lower the value, the better it is. A spatial constraint is accordingly defined as a criterion that determines which areas in the final output map are considered as absolutely not suitable for the proposed development. Poor performance of a criterion can be compensated by good performance of another criterion, which can lead to a good overall 'suitability' in the cumulative suitability map. As opposed to factors, poor performance of a constraint cannot be compensated by good performance of another factor or constraint. These areas will always obtain null value for that pixel in the final output. Criteria that represent protected, inaccessible, or otherwise unavailable, areas are usually made constraints.

An important phase in SMCA is the standardisation of input maps (Meng et al., 2010, Omo-Irabor et al., 2011, Raaijmakers et al., 2008). Each factor that is input in the SMCA process represents different attributes and accordingly has different measurement units. Thus the criteria for determination of combined suitability/vulnerability are represented in different attribute scales and standardisation is necessary in order to obtain a meaningful combination. Standardisation is applied to obtain comparable attribute scales in raw datasets, to allow comparisons among criteria. It involves defining the values of the factor in a 0 to 1 range using the appropriate function to create a membership degree (gradient). This process usually requires professional and/or expert local knowledge.

Weighting of factors is the process by which stakeholders (or experts) prioritise factors by their importance to the required resultant intent. In order for the weight values to be combined meaningfully, the process of normalisation is carried out by dividing the weight allocated to each factor by the sum of the weights at that stage.

The output of an SMCA process is one or more resultant maps, in which each pixel in the map indicates the combined suitability/vulnerability/effect of the factors and weights that were included as input in the analysis. Mathematically this can be represented by the formula:

$\sum_{i=1}^{n} wi * xi,$ **Equation 3.1**

where w_i is the normalised weight of the factor x_i, which is represented by a standardised raster map.

Hill et al. (2006) demonstrate a spatial multi-criteria analysis using the example of grazing potential in Australia with respect to environmental factors. Figure 3.1, modified from the example of Hill et al. (2006), describes the SMCA process. The red boxed maps indicate individual factors that are combined using weighted summation to form larger "group factors" (blue boxes), which may again be combined to form "thematic groups" (green boxes) which when combined will produce the final resultant combined map (large purple box). The reader's attention is drawn to the factor in red oval - it is a constraint.

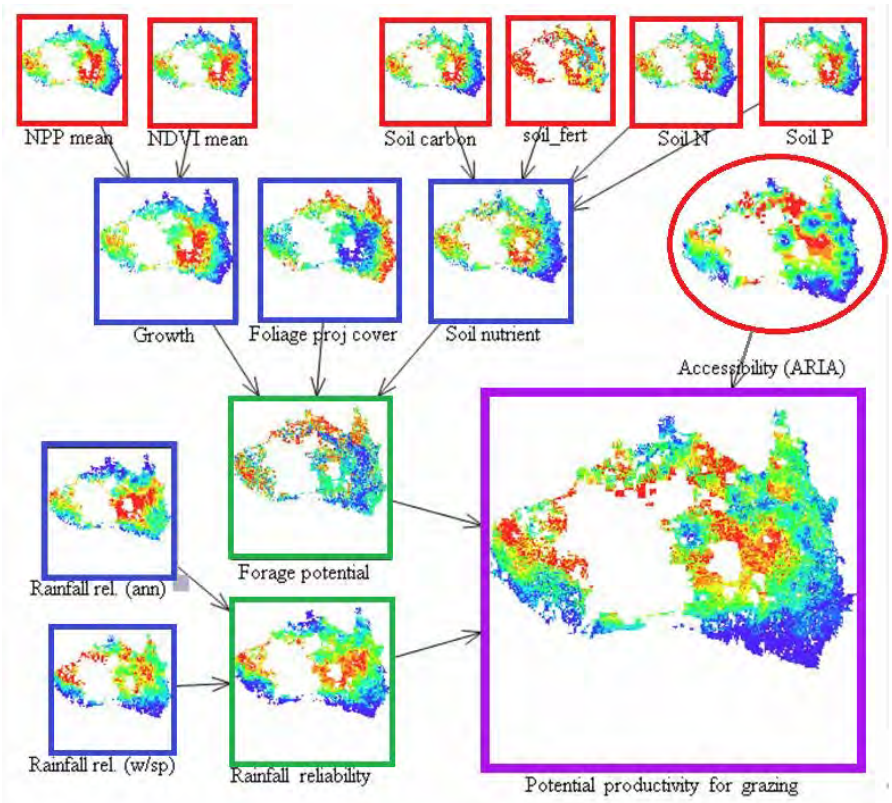

Figure 3.1: SMCA process for evaluating grazing potential for livestock in Australia (Adapted from Hill et al. (2006)).

4 A boundary object on scale

A transdisciplinary framework for understanding and communicating scale choices.

Highlights

This chapter is about the issue of scale.

Scale carries important implications in real life planning for the credibility, salience and legitimacy of the planning process and its outcomes.

However, despite copious amounts of research on it, it still remains largely un-understood and is underutilized in the planning and assessment processes.

This mainly because research in it has stayed steeped in individual disciplines. A transdisciplinary perspective and understanding of scale is needed.

Boundary objects, frameworks which are flexible enough to apply to across different disciplines and yet robust enough maintain the core ideas, offer a means to do so.

A 3-dimensional boundary object which can help to better understand, express, negotiate and resolve issues of scale in reality, models and data is proposed here.

This chapter based on an article in review as:

KESHKAMAT, S. S., KOOIMAN, A., ZUIDGEEST, M. H. P., VAN DER VEEN, A. & VAN MAARSEVEEN, M. F. A. M. 2011. A boundary object on Scale. Ecological Economics (Accepted pending minor revisions).

4.1 Introduction: The boundary concept

This chapter briefly introduced the proposed means to achieve the research goals from the methodological perspective. The following chapter will deal with the boundary object on scale.

Applied research and assessment generally follow a path which consists of 3 main components, in which scale choices are being made. Mirroring this, the available literature on research into scale-issues also falls into corresponding 3 main streams:

1. Sorting and understanding of scales and patterns in real-life. For example, habitat fragmentation studies in landscape ecology, impact assessment of anthropogenic activities, land-use zonation in regional planning etc.

2. The simulation or modelling of real-life issues (for example molecular modelling, risk modelling, hydro-geological modelling, atmospheric aerosol transfer modelling etc.) in order to find solutions for real-life issues (that may be applied back to real-life), or depiction of real-life through maps).

3. The collection of data to confirm, refute, extrapolate and extend the models (for example, remote sensing of vegetation & urban areas by interpreting their reflectances).

Accordingly, we propose a hypothetical 3-dimensional framework (Figure 4.1), whose three axes are: “scale of reality”, “the scale of model” and “scale of data”. These axes represent the streams in scientific literature on scale – reality, models and data/depiction, which we define as axes in a 3-dimensional scale-space.

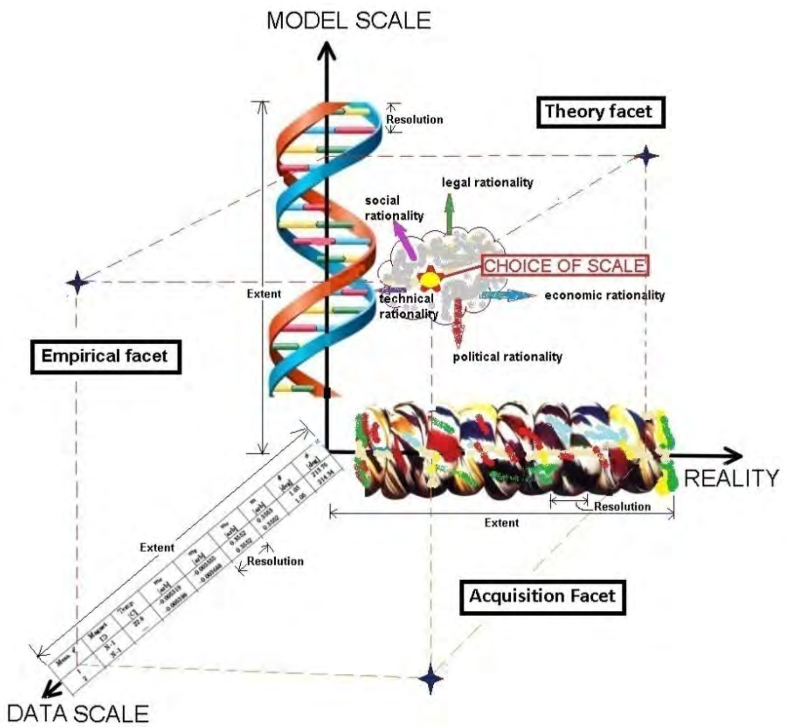

Figure 4.1: The proposed boundary object on scale-choice, and its components.

We then apply the two lenses (of extent and resolution) to the axes-framework, defining that each axis has its own pair of resolution and extent. As per standard definitions, the 'resolution' would be the smallest detail that can be shown on the axis and the 'extent' is the maximum range that can be shown on the axis. Similar to Cartesian geometry, the choice of resolution and extent on each scale axis can and may be independently different. The exact combination of resolution and extent chosen for the axis depends on a variety of rationalities at play in the process of scale choice, and may (as seen in Figure 4.2) consist of large extent-low resolution (for example global climate change studies), high resolution-low extent (for example molecular material sciences), or low resolution-low extent (project feasibility or reconnaissance studies) and more rarely, high resolution-large extent[7].

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[7] From Goodchild et al., we know that resolution and extent are inversely proportional to each for managerial reasons – if not for economic reasons, then at least purely for

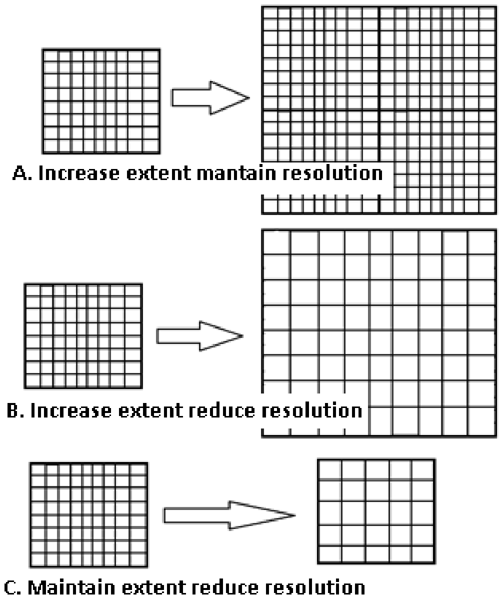

Figure 4.2: The relationship between resolution and extent.

4.1.1 Scale of Reality

Reality consists of several different processes acting in a space-time continuum. The processes have different scales - different start points and/or different extents and/or different resolutions. There are therefore different perceptions of reality and different interpretations that can be drawn from even the same process by observers, depending on their own location in the space-time continuum. The interactions between different processes further complicate the interpretation. Systematic assessment and planning therefore define the exact window of the study – the choice of processes to be studied, their start-point, their extent and the level of detail – before modeling or analyzing them. We term this 'window of study' or 'focal zone' as the scale of reality.

Sheppard and McMaster (2004), Sheppard and Leitner (1999), Marston (2000) Marston and Smith (2001), Turner et al. (1990), Prakash and Gupta (1994)

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processing and storage capacities. However in recent years, cloud computing, distributed processing etc. have hurdled these technical limitations and challenging studies using high resolution as well as large extent are being taken up more often.

argue that space and scale, like territories, are social constructs. Herb & Kaplan (1999) in 'Nested Identities: Nationalism, Territory and Scale', went a step further and combined theoretical insights on scale and political sciences with 13 structured case study examples to remind us that the scales and identities are inseparably connected to each other. The book explicitly examined how human identity relates to territory and how it coexists and competes with other identities (global, national, regional, cultural, religious etc.) at different geographic scales. These scales are not only fluid, but also interconnected or nested and are implicitly used by actors (both proponents and opponents) in the negotiation of identity within the complex nexus of territory, power and scale.

Integrated Assessment studies such as global environmental change modelling (for example, Turner et al. (1990) and Wilbanks (2006)) must find the balance between modeling real-life at micro-scale (high resolution- less extent) which will provide opportunity for holistic analysis that is not possible at larger scales; and modelling macro-scale processes (coarse resolution- large extent) which illuminate inter-dependence and interactions that would be completely masked at smaller scales. However, managerial rationalities at play in any project dictate, from the needs of practicality, that it is not possible to study the phenomena at high resolution and large extent - there must always be a compromise; but the concept not only exists theoretically, it is the only reality: Real life processes take place at high resolution, as well as large extent. Wilbanks (2006) too argues that lessons from assessment indicate that there is not one scale for every purpose and scale is related to function. Thus, since reality is about perception and perspective, the scale of reality can be defined as phenomena, processes and issues as perceived by stakeholders, or framed by managers and decision makers. It thereby aims at the creation of knowledge and forms the context for it.

At a practical level, the scale of reality defines the scale of the research and managerial problems and, the derived research and managerial objectives. This frames the requirements for the scale of methodology and models.

4.1.2 Scale of Model

A model, usually defined as a simplified representation of reality, is a human construct to help us better understand real world systems. There are four main types of models, which can, depending upon their applicability, be divided and subdivided into several sub-types. Figure 4.3 below, shows the main model types and examples.

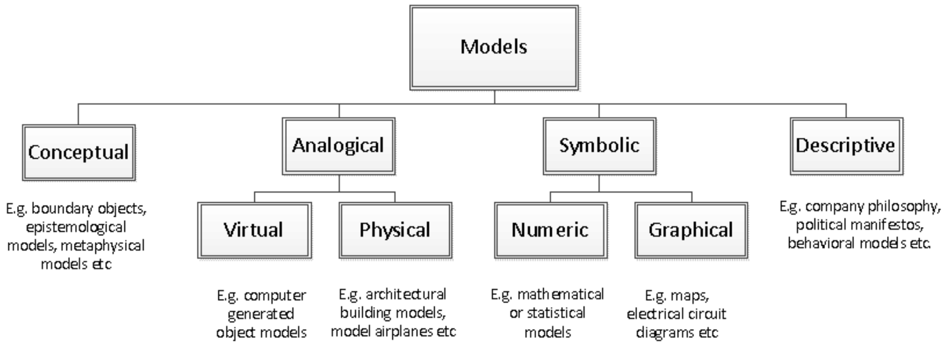

Figure 4.3: Main model types

Regardless of the type of model, scale plays a very important role in the development of a model – either explicitly, implicitly or both. The model scale axis represents the scale with which reality is translated into cause-and-effect relationships of processes and decision making. In science it‘s focus is on causal relationships. In management and in the political world, the model scale relates to the instruments of stakeholders and is therefore closely linked to the administrative or institutional scale. The models therefore also predicate what would be the effect of decisions on issues under observation.

Apart from the extent and resolution of the reality sought to be studied, framing of model scale manifests itself especially in the definition of indicators. Models are important tools in assessment and frequently get rescaled based on the application. Like maps (Monmonier, 1996), models can be used to both hide or reveal scale-dependent relations (Lebel, 2003). Framing model scale by using objective criteria for indicators and variables is therefore crucial in salient assessments and planning.

4.1.3 Scale of Data

The Oxford dictionary gives the meaning of data as *“facts and statistics collected together for reference or analysis”*. In computing sciences, data are numbers, words, images, etc., accepted as they stand. Beynon-Davies (2009a, 2009b) and Case (2007) separated the concepts of data, information and knowledge based on the level of abstraction, and state that the hierarchical relationship of these three concepts is that data is the lowest level of abstraction, information (data+ meaning) is the next level, and finally, knowledge (information+ inference) is the highest level among all three.

The most commonly used definition of data is *"qualitative or quantitative attributes of a variable or set of variables"* (Wikipedia, 2010). It is the measured (observed or perceived) attribute of the manifestation of reality. Scale of data thus connects the scale of reality to the scale of the model, for example - the x, y, z coordinates are the vector attributes of a manifested process, whereas temperature, humidity, height, density, reflectance are their scalar attributes. This estimation is influenced by the extent (range) and detail (precision) needed i.e. the scale of data. For example land-use classification done at a county level will often be very different from one done at supra-national level, in terms of not only spatial extent and resolution, but also importantly in the class descriptions.

Depending on the attribute to be recorded, data scale can be categorical or magnitude [8]. Categorical records are instances on a scale that can be distinguished from each other absolutely (e.g. thematic or Boolean data). Magnitude refers to the property that one instance on a scale can be judged greater than, less than, or equal to another instance on the same scale (E.g. ratio, interval, ordinal or nominal data types).

4.2 The boundary object

It was seen in previous sections that research till date has been focused on understanding each axis, and within the bounds of the respective disciplines the understanding of each axis, particularly the data and model axis, has more

[8] Meta-data, often called information on data (FGDC, 2000), forms a special class of data which we see more as a description of the data, and the data acquisition process, rather than a recordable attribute of a physical phenomenon. It helps give the rationale to scale choice, but does not have/need a scale itself. Therefore we do not include it in this boundary object we propose.

or less reached a plateau. The attempts at understanding relationships between any two scales (axes) too have been made, but are much fewer. However, the framework that we present here incorporates all three axes and the facets which represent the interactions between any two axes. There are three axes and three facets. Although we will describe the three axes briefly, they have in general been delved deep into by previous research. We believe that the interactions, i.e. the three facets, are of greater importance to this discussion than the axes themselves. Consequently we contribute to the discourse on scale choice by emphasizing the interactions rather than the individual scales. The facets are:

- The Theory facet –representing the interaction between reality and model scale
- The Empirical facet – representing the interaction between model scale and data scale
- The Acquisition facet – representing the interaction between reality and data scale

The principles of human rationality, as defined by Diesing (1962), will be used to understand how a specific scale will be chosen/selected when there is an interaction between any two axes. Diesing specifies and explains 6 basic types of rationalities: technical, economic, social, ecological, legal and political. These rationalities reflect 6 principal types of goal-based, reason-enabled effectiveness in society. They guide various trends of development, group gravitation (interest-group formation) and decision-making. Depending on which rationalities are at play in each interaction (facet) and which rationality is (pre)dominant, the choice of scale in that facet occurs[9].

4.2.1 The Theory Facet - interaction between reality and model scales

The theory facet brings out the compromise that must be made between reality, as it truly exists, and what can be practically modeled by us (Ewert et al.,

[9] Other rationalities mentioned in actor network analyses are scientific rationality, managerial rationality and design rationality, which are in essence included in Technical and Economic rationality.

2006). Actors typically operating in and affected by this facet are research scientists, modelers, physical geographers, systems analysts etc. However it is typically within this facet that politics and power contend and play a major role, particularly in projects involving common goods. It is in this facet that we would place the work of Delcourt & Delcourt (1988), Levin (1992), Joao (2002), Sayre (2005), Lebel et al. (2005), Cash et al. (2006), Karsten (2007) all of whom through their own separate disciplines pursued a line of inquiry that we interpret as having commonality – researching issues to explain and guide the use of scaled simulation of real life contexts. Following the line of reasoning of Beynon-Davies (2009a, 2009b) and Case (2007), in this facet inference is added to information so that meaningful knowledge is created and decision making is supported.

Levin (1992) states that one of the principal techniques of scientific inquiry is to change the scale of description by filtering out individual cases that are unrepeatable or unpredictable phenomena. In doing so, we trade off heterogeneity and loss of detail within a group in order to gain some degree of modelling predictability, thereby extracting prominent features of phenomena at finer scales as variables at other scales. He emphasizes that the problem is *"not to choose the correct scale of description but to recognize that change is taking place on many scales at the same time, and that it is the interaction among phenomena on different scales that must occupy our attention*". Taking the example of krill distribution in the southern oceans, he shows how it is possible to model even a system operating at multiple and complex scales, by recognizing which variables produce the observed patterns. Through it he proves that the philosophy behind the applied models is not that finer detail does not exist, but that often it is not relevant (or needed) to show the observed patterns. This is the kind of simplification we need in order to identify the scale of operation of real phenomena, as well as the different scales of interactions of inter-phenomenal processes[10]. After all, the goal of scientific

[10] We prefer not to use the term 'cross-scale phenomena' in this facet, because the scale of reality is a continuum not at static levels, although of course the scale of the modelling of it may be so due to the *"lumpiness"* that we visualize for our understanding.

research is to simplify complexity and represent the essence of reality and its processes, understandably.

We call this facet as the ‘theory facet’, as this is where the researcher/analyst chooses which/how much part of the system s/he would like to study and model and at what detail. It should however also be noted that the interactions in this facet are not unidirectional but bidirectional. The reverse of the process of modelling, i.e. validation, is the process flow in the opposite direction in this facet.

Scientific rationality, political rationality and managerial rationality are the main contenders in (typically) heated debate in this facet. However, legal, social, economic, technical rationalities are not too far behind. Understandably, as complex is the reality under study, so complex will be the interplay of rationalities in it. Examples of pitfalls of inappropriate scale selection in modelling of reality are: important hotspots overlooked in ecology, vulnerable groups and situation overlooked in disaster risk management, poverty alleviation efforts misdirected due to poverty assessment models or, infrastructure investment assessments that can be analysed to show wide-ranging benefits, while actually benefitting a few at large costs to many.

4.2.2 The Empirical Facet - interaction between model and data scales

In the previous section a researcher/analyst has chosen which part of reality is to be modelled and there-from created an analytical ‘logic-driven’ engine, which through the mechanism of equations built into it will mimic (or try to mimic) a certain process of reality. It is then time for the system to take on board values, i.e. data that represents the variables within the equations. This is the process of data integration, in colloquial terms called ‘running the model’. We call the facet in which this interaction between the model and data scales takes place as the ‘empirical facet’. In this facet the data scale is linked to the model scale which converts collected data to information by adding meaning and interpretation to otherwise neutral facts.

In this facet, the user/modeler chooses what data is needed to represent the parameters (variables and constants) within the model. Like in the previous facet, the interaction is not unidirectional – the scale of the model will decide what data is needed, but it is often also conversely true (usually from practical constraints) that data availability will decide what should be the scale of the model. This facet thus represents the compromises and choices between what we would like to model, and the amount of resources (computing and storage capacities and time) that we can allocate to it. However, unlike the theory facet where there cannot be a 1:1 conversion between the two axes (reality and model), in this facet the data should be made available to the model's scale, or the model must be scaled to the data – the connection is rigid.

It is perhaps because of this rigid connection that most disciplines and most researchers do not see them as individual entities, but as one. We however emphasize that there is a conscious process of selection and compromise that is gone through when deciding how to match the data to the model and vice-versa. There are some models which are trans-scalar but even for these, the data that we need to 'feed' them has been acquired and stored at their individual particular scales (resolution and extent). Thus, although the model itself may be conceptualized as trans-scalar by nature[11], because of its rigid connection with the data scale, its implementation can never be trans-scalar – iterative separate implementations of it by entering data of different scales into it, and subsequently integrating the results may be the closest that we can come to achieve a multi-scalar result.

One of the potential pitfalls, however, of this interpolation, upscaling and downscaling of data to match the model, or vice-versa, is what Levin (1992) calls the key to understanding how information is transferred across scales, i.e. what information is preserved, and what is lost as one moves from one scale to another. He says that the simplifying-notion is that only certain prominent statistical characteristics of predominant lower level phenomena, i.e. the extracted meanings from the data, are transferred to the higher level, i.e., information. This notion also explains why information may appear distorted or noisy when upscaled or downscaled from its original context.

[11] In our opinion, no model can claim to be truly trans-scalar because the choice of scale (what to study, and at what detail) must already have been made in the theory facet. By discarding phenomena/opinions/objects from our model's 'system boundary' we have intrinsically (and implicitly) set a scale to the model.

Data may carry different information when used at different scales, recognized in 'hierarchical model' and 'emergent properties' opine Allen and Starr (1982), Golley (1989). Each level of the hierarchy has unique properties that are not a simple summation of the disaggregated parts at the lower level. This debate can also be found in remote sensing image interpretation approaches. For example Blaschke (2010) who argues against the paradigm of 'the finer the pixel resolution, the better will be the classification', calls for 'object-based image analysis' at appropriate (coarser) resolutions in order to classify images with greater accuracy. Scientific (technical), economic and managerial rationalities usually play a strong role in this facet.

4.2.3 The Acquisition Facet- interaction between reality and data scales

Primary data collection is the most time consuming part in many studies, investigations and censuses. Sampling strategies are developed to reduce time and cost of data collection. Similarly secondary data, maps, imagery, thematic data, maybe very expensive and these costs may be prohibitive in assessments for institutions without appropriate budgets. Hence we can observe cross-pulls and conundrums similar to the one that affected the model scale axis on the data scale axis. The data scale axis undergoes influences from the reality axis, while at the same time needing to fulfill the choices and compromises demanded by the modeling axis.

The key rationalities at play in this facet are the technical (or technological) rationality and the economic rationality. Data is generated every time a certain attribute of a phenomenon, or an opinion of a respondent, is recorded. This data can be of several types. From the field of computer sciences we have such types as integer, floating, character, Boolean pointer, strings, but there are of course others. From the field of social sciences we also get such data types as concerns, priorities, feedbacks etc. From the field of geo-information sciences, data can be spatial data such as radiance/reflection in an image, locational information etc. From artistic disciplines come data such as scents and tones.

The costs, capabilities and limitations of our measuring (and recording) instruments are the determining factors of the data scale axes. It is known that for most measuring systems, resolution is inversely proportional to the extent i.e., in general, the more detail an instrument is able to measure, the less will be its measuring range. It is also usually true that greater the extremes (sensitivity/range) that are needed, the higher are the costs needed to generate the data. For example, high-precision measuring instruments are known to be more expensive than standard precision, but so too are instruments to measure large-range. Economic rationality thus plays a key role.

On several occasions however, regardless of the costs we are willing to pay, the technology needed to produce the precision or swath coverage we desire, just does not exist. It is then that technical (and/or technological) rationality that comes into play. In the fields of social sciences, wherein data measurement is through the collection of feedback (questionnaires) from stakeholders, the resolution (whether individual-level, household-level, locality-level, city-level), as well as the coverage extent (household–level, locality-level, city-level, county-level etc. respectively), will decide the cost and feasibility of the data acquisition. Managerial rationality, more often than not, then plays a key role in the selection of the scale of data collection. Other prominent issues include copyright, data ownership, privacy and security[12].

4.3 Discussion and reflection

By making the issue of scale selection throughout the process explicit, the outcomes are better informed and more salient. Expert practitioners in the field have been known to have an implicit understanding of scale and the influence of different rationalities at play in its selection. However, unless this process is made explicit, it lacks the transparency needed for credible decision support, legitimate stakeholder participation, salient governance and sustainable decision making; even worse, it may be used with vested intentions by the proponents. However, the most common instance, is when the choice of scale, in a real-life situation (for example, infrastructure planning) which

[12] Copyright and data ownership are important issues that determine access to and scale of secondary data; Privacy is an issue for social and economic data that can be related to individuals, households, properties and farms and since location can be used to obtain identities, much information is made anonymous by aggregation to a coarser scale; Access to fine scale data is the subject of national and public security concerns and often affects its availability - usually only coarser scale data is available for open access.

may affect the very fabric of the social, ecological and economic environment of the area, is done not from any other rationality but the managerial one – expediency, i.e. “whatever is the scale of available data”. These are the most important reasons why a deeper consciousness of scale must be instilled in all fields of science, assessment and planning, than there is at present. Quattrochi & Goodchild (1997) commented that the problem of scale has reached a plateau and that most is better understood now with the advent of GIS. Far from it, we believe there is clearly some way to go before scale effects can be fully understood and accommodated, but this chapter has aimed to be the next step in that vital process.

Referring back to Figure 4.1, with the above descriptions, we can identify the inter-axes processes and “flows of meaning” with more familiarity, as shown in Figure 4.4 below. When we try to apply meanings from reality and identify a model scale, the process is called modelling. Conversely, when we use our model to verify it against the reality, we usually call this model validation. In the Empirical facet, we identify data of a particular scale which we integrate into the model to “run” it, thus the flow of meaning in this process is from the axis of data to the model axis. If however we force our model to fit the scale of the data available, such a process would be called data fitting. In the Representation facet, when the flow of meaning is from reality towards identification of the scale at which data will be gathered, it is part of the process of measurement; and when it is the other way round, it is the process of (instrument) calibration. At the same time, within each facet are seen the iterative processes of learning- doing-relearning-refining – for example, the choice of a modelling scale is not an open-and-shut decision, but an iterative process between reality and model scales in which different rationalities play a role. Similarly the choice of the representation scale is also the result arrived at through intra-facet deliberation of the various rationalities (mainly technical and economic).

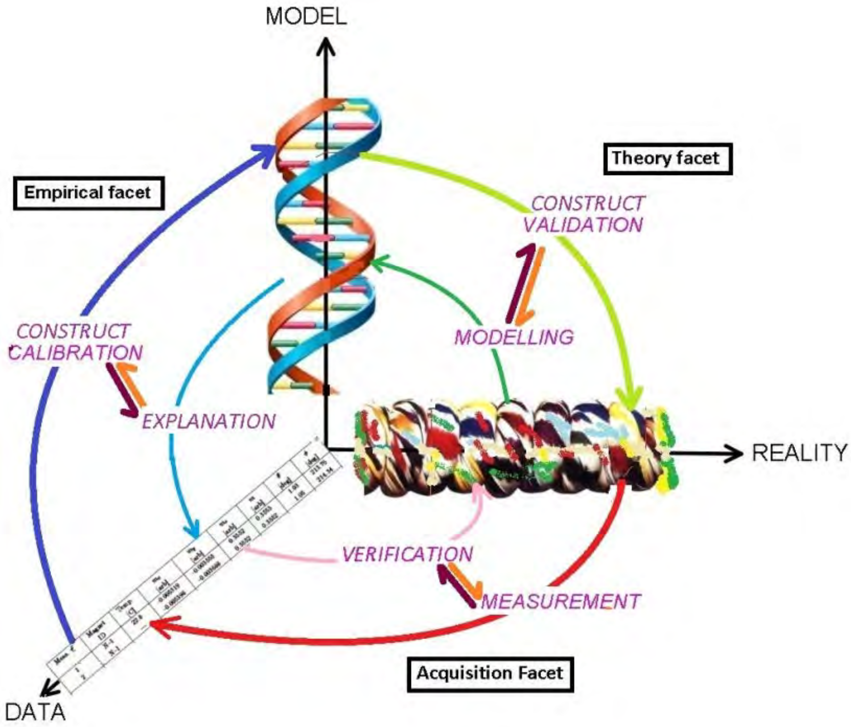

Figure 4.4: Processes and interactions with respect to the proposed boundary object on scale-choice.

Using this boundary object, it also becomes possible to see why it would be erroneous to plan the scale of a real-life intervention process based purely on the scale of available data, as is often done with a view to expediency. This framework helps to resolve the 'problem of scale' into its component blocks. It can help make better sense of abstract concepts such as trans-scalarity and glocal identity. It also can help to identify whether, why and how the choice of scale is data-driven, issue-driven or model-driven, and if need be, necessary remedies or informed negotiations can be taken up. Thus it aids transparency and consensus building, the core goals of multi-stakeholder participatory processes.

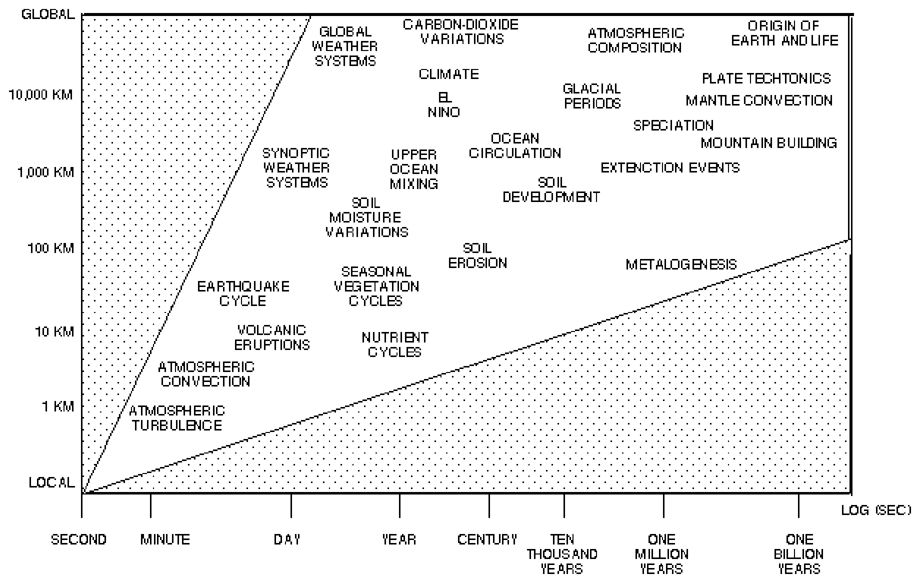

Figure 4.5: The relationship between characteristic spatial and temporal scales in earth system processes (Source: Johnston & Hudson, (1989)).

Typically discussions on scale have centered on the aspect of geography (i.e. space and spatial data) (Moore, 2008). However, in keeping with Gibson et al.'s (2000) meta-definition of scale, our discussion and framework also keeps in mind the temporal and hierarchical aspects, which although even more difficult to account for, can be simplified by their link to spatial scale. We believe, like Delcourt & Delcourt (1988) who argue that spatial and temporal scales usually co-vary in natural systems, and Jordan & Fortin (2002) who contend the same for economics, that infrastructure plans involving large spatial extents will generally also be planned for larger time periods and vice-versa. For example, time scales in planning of large-investment transnational highways typically range in 20-30 year periods, provincial infrastructure plan periods may lie within a 10-15 year period, while county-level planning generally focuses on a sub-10 year period. Partidario (2007) also showed how the temporal scale is importantly connected to spatial infrastructure assessment processes. Figure 4.5 shows the relationship between spatial and temporal scales in earth system processes.

4.4 Conclusions and recommendations

Within the fields of assessment and planning, the question of scales has been of ongoing interest since the 70s but discussions of 'smaller is better' vs. 'larger is holistic' are as yet far from solution (Newman and Dale, 2009). The framework defined herein created room for a new approach to understanding the complex 'problem' of scale. When carefully observed, this framework will show stretches of confluence with the three major currents of thought in complexity (Manson, 2008), viz. aggregate complexity, algorithmic complexity and deterministic complexity but in a manner that may be understood and negotiated by users who are not steeped in theoretical philosophies.

Choice/ Power equations for scale wars if they may so be called, for each facet as well as a generalized cumulative power equation can be defined mathematically. As Karstens (2009) concludes in her thesis "scale choices in multi-actor policy analysis", there is no '*right scale*' – the context defines the choice, and despite that, or perhaps because it is so subjective, it is necessary to make explicit the reasons why such a choice was made, which is the very same goal of this chapter too. An informed decision forms the basis of sustainability; information for "informed" decision making has to be apt for decision makers (salient), be scientifically valid (credible) and represent issues of relevance to and recognized by stakeholders in society (legitimate).

The boundary object presented in this chapter presents scale as a framework that is defined by three interdependent axes: the axis of scale of reality and context, the scale of models and methods and the scale of data. The interactions between these axes are described as three facets. We define "appropriate scale" as a scale that is defined and balanced in each of the three axes, considering the demands, possibilities and limitations as defined in each of the three facets. By considering the framework in its entirety the problem of scale can be can be handled, and salience, credibility and legitimacy of assessments and plans can be improved. The conscious use of this boundary object to balance attention across reality, models and data can help scientific inquiry in bridging the gap to practice.

5 Strategic corridor planning

Highways as an institutional tool to address strategic developmental goals.

Highlights

Scale plays a key role in the planning process. This chapter takes the case-study of the planning of a corridor trajectory using geospatial techniques and technologies.

From the perspectives of feasibility and sustainability, it is as important to consider national goals in the planning as well as international ones.

A multi-tiered SEA-like methodology is used to understand and identify what should be the goals and stakeholders considered in the planning of a mega-highway.

Some of these goals are complex multi-level policy goals which need to be operationalized in order to conduct geospatial analysis which can meld stakeholder concerns and priorities.

The outcomes of this planning process are corridors which are aligned to broad policy goals. In lower tiers these corridors will be used to limit and identify route alternatives, and then to prioritize projects.

Thus, positive impacts can be maximized and negative impacts can be minimized at each scale level at policy and plan tiers.

This chapter is based on an article in preparation as:
KESHKAMAT, S. S., et al.. 2011. Strategic highway corridor planning. *Journal of Transport Geography* (In preparation).

5.1 Introduction

The introductory chapter dealt with the practice of planning and assessment of linear infrastructure and raised the issue of scale especially in the planning of mega-highways. Chapter 4 picked up the issue of scale and demonstrated through a boundary object a technique that can provide planners, stakeholders, researchers and decision makers a way to deal with the issues of scale in a holistic manner which addresses the reality, models and data. This chapter furthers the discussion, taking the case-study of the corridor-planning of a long distance highway in Mongolia, a landlocked country in north-eastern Asia using broad strategic goals and large geographical extent, for serving the needs of stakeholders at different scales (local, national and international) in the context of the policy and plan tiers.

The highway on whose case study this chapter will be based is one of three international highways proposed by the United Nations Economic and Social Council for Asia Pacific (UNESCAP) to cross Mongolia under the Asian Highway Network plans. Taking the planned highway as the real life example, and based on actual field observations and available policy documents alternatives based on this methodology will be developed. Hence, although the alternatives are hypothetical they are of potential use for the decision makers.

Very sparsely populated, Mongolia is the 4^{th} least densely populated country in the world, but despite this sparse population, and particularly due to the large distances that separate population centres, is there a dire need for the development of transnational connectivity. The need is not only social and socio-economic, but also ecological, because in the absence of formal roads vast swaths of landscape are being degraded by dirt road propagation. At the same time, the connectivity conceived by the UNESCAP under the Asian Highway plan in 1958, has been evolving keeping in mind the role that Mongolia plays in the context of its geographical location in north eastern Asia. However, although such trans-Mongolian east-west connectivity is direly necessary, both nationally and internationally, a feasibility assessment based purely on current traffic demand would not justify the enormous financial investment entailed in bridging such vast distances (about 3000km east to west), and so all possible alternatives need to be explored in depth.

Given the cost implications, the possibility of construction of two separate east-west highways, one for national and the other for international needs, in this country is financially and logistically rather remote. Hence, a single east-west highway that can efficiently serve local, national and international demands is needed to ensure its social and political objectives, financial viability and ultimately its operability (Button and Nijkamp, 1997, Button et al., 1998, Nijkamp et al., 2003, Van Veen-Groot and Nijkamp, 1998). For example, a highway that is aligned purely to local interests may end up at border locations that are neither in national interest, nor at locations where there is existing connectivity from the neighbouring country.

A situation like this is one which every land-locked country, such as Mongolia, wishes to avoid as much as possible (UNESCAP, 1999, UNESCAP, 2003b). On the other hand, a highway designed purely as per national and international interests could seriously degrade the quality of life in local regions which are intersected by such a highway. Lessons can be drawn from the Djibouti-Addis Ababa highway conceived as a grand economic corridor in an impoverished region, but now nicknamed the “AIDS Highway” due to its reputation as the corridor from which HIV-AIDS and other STDs spread into the hinterlands of east Africa (Brushett and Osika, 2005). Not just social, it has also been proven that highways aligned without comprehensive analysis of considerations on its trajectory can even affect the economy negatively due to loss or degradation of ecosystem services or direct deprivation of income-generating capabilities along the trajectory due to land-loss (Taaffe et al., 1996, Rodrigue et al., 2009).

This brings back an important issue in transportation, and particularly highway planning – the issue of scale. Highway planning involving large distances comprises multiple stakeholders, administrative and geographical levels and therefore needs to be planned at multiple tiers. This is because, although the outcomes of each of these tiers will necessarily have to be nested spatially, mostly the goals in the tiers are never nested. A thorough analysis at each higher tier would enable a development process which tries to fulfill the development goals of each upper administrative level and yet, within the ambit of the developed alternatives, still leaves enough worthwhile choices at lower tiers and lower administrative levels.

SEA can be a rigorous and efficient means to do so (Dalal-Clayton and Sadler, 2005, Fischer, 2002, Jansson, 1999, Sheate, 1992), and even though it is not yet a legally mandatory process in Mongolia, a SEA-like thinking can aid the planning process greatly. It is not the aim of this chapter to conduct an SEA, but to show how SEA-like thinking in combination with spatial multi-criteria assessment, GIS, remote sensing and a deeper understanding of scale issues can help to better the process of highway planning. The method offered in this chapter demonstrates a tool to enhance the process of corridor planning.

Since the highway has both national and international interests, this case study will study the problem at international level i.e. national and surrounding nations. However, the corridor alignments to be proposed are only limited to sections within Mongolia. Hence the model specification will take the reality of the international level and convert it into a model applicable within the Mongolian national context. The data, corresponding to the model specifications, will also be limited to national boundaries, but in a manner that can still draw correspondence with the included international interests.

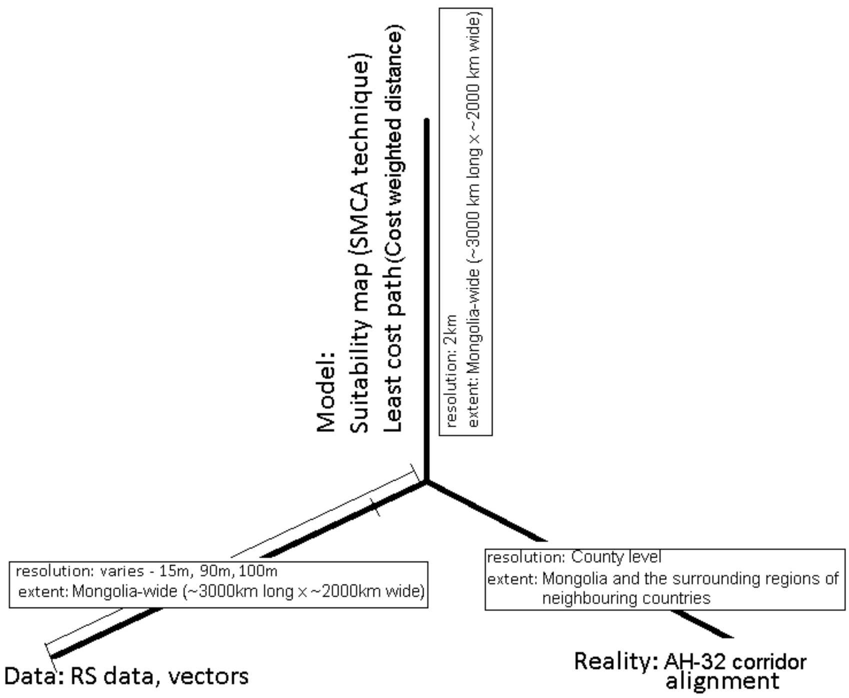

Figure 5.1: Positioning the case study

5.1.1 Description of the study area

Mongolia[13] (shown in Figure 5.2) is a landlocked country in north-east Asia, bounded by Russia on the north and China in the South. As per national statistical estimates (2008) the population density of Mongolia is 1.7 person/km^2. However, the actual population density is much lower than this figure for most of the country, as the capital city Ulaanbaatar itself contains 1.2 million of its 2.9 million people and a further 0.8 million live in the other three major cities (National Statistical Office of Mongolia, 2008). This leaves the countryside extremely sparsely populated. Combined with the vast distances and poor economic conditions until recently, this reason has contributed to the lack of nationwide formal road infrastructure in the country. There is a total of only about 2600 km of asphalt roads for 1,564,115 km^2 of land area. Much of the transport in the country is only by using 4-wheel drive vehicles on dirt tracks, making travel within the country very difficult in general. One of the direct effects of this constraint against travel is the reduced accessibility to employment, proper health care and adequate education.

Since democratization in 1990, the Mongolian economy has seen a steady economic growth and, like other developing countries, is seeing the corresponding rise in vehicle numbers and vehicle usage. However, investment in construction of asphalt roads has not seen a corresponding increase due to more important national priorities, but also because of the vast distances involved. However, the dearth of formal infrastructure support for the increased vehicular traffic widens the dirt-tracks into dirt-roads and thence into dirt-road corridors and is also leading to long term socio-economic losses due to the environmental degradation.

[13] Note: All maps of Mongolia in this chapter are in UTM-48N projection.

Figure 5.2: Physical map of Mongolia (Source: Mongolia Tourism, 2009)

Observation of the trajectory of these corridors shows that their objective is to try to achieve connectivity between provincial capitals and Ulaanbaatar; between various provincial capitals; and between provincial capitals and their surrounding regions. However, less than 700km of the 38,000km of roads connecting different province centres is paved, and there are only about 360 bridges throughout the country. The Mongolian rail network, only provides slight relief from this tyranny of distance and comprises 1,815 km of broad gauge track, of which 1,110 km are on the main line linking Russia to China (Trans-Mongolian main line), while 239 km are on a line in Eastern Mongolia connecting the eastern regional centre Choibalsan to Ereentsav. (The remaining 477km are branch-lines). There are only a couple of large rivers capable of providing perennial navigation, and so river navigation is not considered as a viable mode of transport, whereas domestic air-transport is prohibitively expensive for the common populace.

5.1.2 The AH32 (Mongolian Millennium Road)

The Asian Land Transport Infrastructure Development (ALTID) project is the Asian counterpart of the Trans-European transport network (TEN-T). The Asian Highway (AH) network (Figure 5.3) is one of its three pillars along with the Trans-Asian Railway (TAR) and seamless transport facilitation project and development of intermodal transport terminals (UNESCAP and Hodgkinson, 1999, UNESCAP and Asian Institute of Transport Development, 2007). The AH network consists of the development of over 141,000 km of highways throughout Asia, seeking to alleviate the geographical handicap of land-locked countries, to aid development and also to provide alternative international trade routes to coastal countries. Agreements have been signed by 32 countries to allow the highway to cross the continent (UNESCAP, 2004, UNESCAP, 2001) and also reach to Europe (Skayannis and Skyrgiannis, 2002, Tsamboulas and Kopsascheili, 2009, UNESCAP and UN Development Account, 2004).

Figure 5.3: UNESCAP plan of Asian Highway network (source: Wikipedia, 2008).

As per naming convention in the Asian Highway Handbook (UNESCAP, 2003a), the highway route names begin with 'AH', standing for *'Asian Highway'*, followed by one, two or three digits. Single-digit route numbers from 1 to 9 are assigned to major Asian Highway routes which cross more than one sub-region, and are of crucial international importance. Two- and three-digit route numbers are connecting highways within the participating countries. The detailed geometric design parameters of the highway depend on classification, terrain and design speed.

The Asian Highway programme specifies that the program will make maximum use of the continent's existing highway routes to avoid the construction of newer ones, except in cases where missing routes necessitate their construction. This is considered necessary from the ecological standpoint, but also the social and economic criteria of land-uses. This will, accordingly, also ensure that most routes will run to already established major international border crossing posts, thus making it easier to address delays at border crossings, which are considered a significant component of the total design travel time.

As seen in the Figure 5.3, three important AH links will pass through Mongolia- the AH3, AH4 and AH32, while one important link - AH6 passes along, and very close to, Mongolia’s northern border. AH3 connects Ulaanbaatar, the capital of Mongolia to the Chinese port of Tianjin, via the Chinese capital, Beijing. The AH32 route designed to be a 2-lane (Class- III) highway, is the main subject of this chapter, running east to west. It also serves an important function as the connector between AH3, AH4 and ultimately the AH6 to the Russian ports of Vladivostok and Nahodka.

The government of Mongolia also considers this link-road (AH32) of high national importance to Mongolia, and is known as the Millennium Road. The *Great Hural* (Parliament of Mongolia) approved the ‘Millennium Road project’ by its resolution No.09 of 2001 and instructed the government to arrange activities associated with the implementation of the project. Steps and legislation were put into place in 2008 to ensure an expeditious implementation of the highway. However its precise route alignment is still subject to hectic political parleys and negotiations. This is partly because there is no ‘existing highway’ worth notable mention in most of the country except in the proximity of the national capital Ulaanbaatar and those connecting Ulaanbaatar to the other major cities of Erdenet, Darhan and Bulgan in the north. It is anticipated that a highway such as this could be the harbinger of economic growth and social connectivity to those provinces that it connects along its route. Based on the UNESCAP’s map, coarse preliminary alignments formulated by the Road Supervision & Research Centre (RSRC) and national Department of Transport are as seen in Figure 5.4.

Figure 5.4: Govt. of Mongolia Millennium Highway plan (Source: (Onon, 2010))

This plan is still considered “preliminary and open” to political parleys and stakeholder protests, however, it does make two main important decisions regarding the origin and trajectory –

a) It must pass through Ulaanbaatar (as specified in the Asian Highway Handbook) where it will connect to AH3,
b) It will connect to AH4 at Hovd, a major regional center in the west of Mongolia.

These conclusions have stayed constant from its inception in the UNESCAP project priority list (UNESCAP, 2006b), regardless of negotiations and discussions about the actual alignment, and hence will be used in this study. The eastern-most node/ border exit/ destination is however not yet fixed, and may be any one 3 border posts in the area viz., Havirga, Sumber or Bichigt. Figure 5.5 shows the border crossings where the highway may potentially cross the border of Mongolia. The following sections will describe the study area – Mongolia, and propose a methodology for the development of the corridor alignment between these locations using different policy visions.

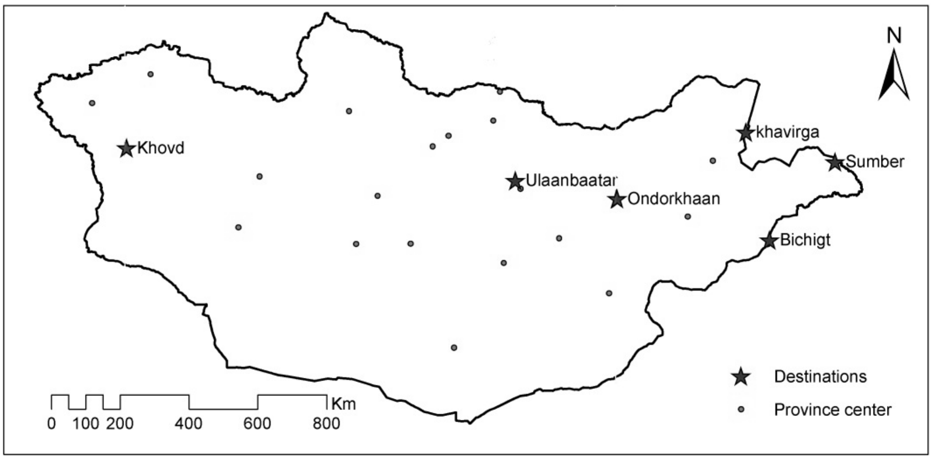

Figure 5.5: Origin-Destination-location map

5.1.3 Planning considerations

As seen in the previous sections, the AH32 will serve, not only as a national arterial corridor, in a vast country with very little formal road infrastructure, but also as a highway connecting other important international highways and locations of high socio-economic importance. Thus the route planning necessarily needs a multi-scalar planning process, such as that provided by an SEA like transport planning. At the same time, it is also necessary to identify key stakeholders and their expectations from this development.

Institutional stakeholders at the highest level consist of development agencies such as UNESCAP, UNDP, World Bank, Asian Development Bank and the governments of Mongolia, Russia and China. However, since for the AH32 will run only through sovereign Mongolian territory, the governments of Russia and China cannot play an overt role in the internal routing of the highway corridor. They can do so only with respect to the point of border crossing of the highway into their own territory. The UNESCAP (2003a) being the organizing agency of the Asian Highway network plays the most defining role. It identifies the following concerns (Figure 5.6) as key for identification of links:

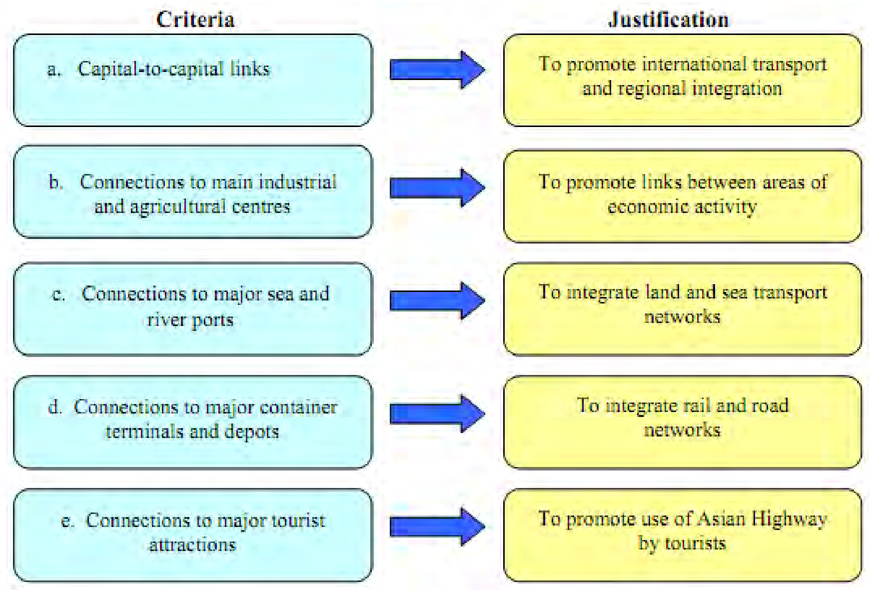

Figure 5.6: Criteria for identification of Asian Highway links (Source: UNESCAP, 2003).

At the same time the Mongolian government (2007) lays down its National Transport Strategy's vision as:

> *"It is the policy of the Government of Mongolia to provide safe, dependable, effective, efficient, and fully integrated transport operations and infrastructure in order to support the social and economic development of the nation by meeting the needs of freight shippers and passengers. This will be achieved by improving levels of service and minimizing costs in a manner which supports Government objectives for economic and social development. All improvement measures will be both environmentally and economically sustainable. In addition, the efficiency of the transport system will be enhanced in a regional context to allow Mongolia to exploit its unique geographical position. The transport sector strategy will be based on moving goods and people, not on moving vehicles."*

It then sets out several specific goals under 6 main themes. Stronger focus is given to general policy and roads, although the potential of rail transport is also recognised as important. The strategy's emphasis is on social connectivity in an environmentally and economically sustainable manner, conforming closely to the principles of the 'Triple Bottom Line'.

Mongolia is also a signatory to the Millennium Declaration and like other countries which endorsed it at the UN World Summit in 2000, Mongolia has defined development goals and targets that meet its specific needs and priorities and is currently implementing policies, plans and programmes aimed at their rigorous implementation. Although it does not appear possible to fulfill the goals by the ambitious deadline of 2015, earnest efforts to fulfill them are being made at various levels of governance.

Development of road infrastructure is identified as one of the most important instruments with which several of the MDGs can be addressed, for example (DFID Transport Resource Centre, 2002, Fay et al., 2005, Hook and Howe, 2005). The planning of (rural) road infrastructure is said to provide people with access to opportunities such as better market prices for farm produce, employment, education and healthcare (Figure 5.7).

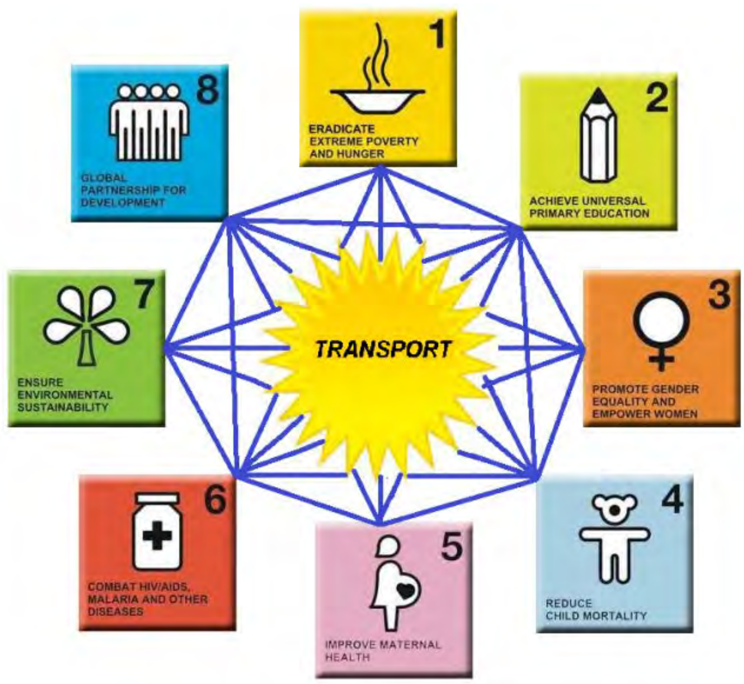

Figure 5.7: Interrelationships between the MDGs and to transport.

Many researchers have written about the positive effects of road infrastructure on the wellbeing of (rural) population. Gannon and Liu (1997) describe the role of transport in poverty reduction as being a complementary one. Like the World Bank, they state that there is a strong relationship between transport and economic development (World Bank, 2011). Rural road infrastructure improvement may have strong effects on social capital, changes in travel patterns, changes in village profiles and land-use, changes in income and welfare (Bradbury, 2006). Czuczman (2000) states that transport plays a key role in poverty alleviation - investments in road infrastructure can be effective in lowering input prices, increasing agricultural production and reducing the monopoly power of agricultural traders by facilitating better access to markets. Using gravity modeling and econometrics, Parpiev and Sodikov (2008) show that for 18 out of the 32 Asian Highway signatory countries including Mongolia, trade can show 35 to 50% increase in value through the Asian Highway network. Forkenbrock and Foster (1990) show how in the United States, considerable interest exists in upgrading highways to help make an area more attractive to new business investment.

Many of these findings are justified; but care should be taken to avoid generalisation, even though various governments and construction lobbyists have jumped on to the bandwagon and disproportionately hyped the strength of the links between roads, transport and economic developments to their vested interests. Increased road constructions by themselves cannot help reduce poverty, create economic opportunity, provide better health care or improve access to education. Transport infrastructure is a prerequisite, although by no means a guarantee, of economic development (Tsamboulas, 2007). Hook and Howe (2005) list 4 important cautions:

- inadequate road networks are responsible for hunger and malnutrition
- road investments will induce economic development
- road investments will alleviate poverty
- kilometers of paved roads per 1000 people is a useful indicator of whether or not a country has an appropriate road network.

They go on to demonstrate that if road developments are taken up with these myths as facts, not only will the interventions not work as intended, the situation may actually get much worse – perhaps beyond reasonable repair

(Howe, 2007). They recommend that road developments be taken up with earnest environmental, social, economic and financial impact assessments. The route planning should be based on these impact assessments and the projects' constructions should be monitored systematically to ensure that they follow the original design intentions. An Asian Development Bank report (Hettige, 2006) shows how rural roads help reduce poverty if they are designed with attention to specific poverty alleviation measures. However, as stated by Van de Walle (2002), only few of the aid-financed rural road projects in developing countries were subject to impact evaluations.

Although many claims have been made on the positive impacts of road infrastructure, so far there has been little research on the socio-economic impacts of road infrastructure route planning. Feasibility studies are often based on financial criteria such as the Internal Rate of Return (IRR), Net Present Value (NPV) or vehicle operating cost (VOC) savings without taking into account economic, ecologic or social criteria (Adler, 1969, Sychrava, 1968). Van de Walle (2002) recognizes that assessing the impacts of rural road projects is a very difficult task, but states that a credible rural road impact evaluation requires baseline data for project and appropriate non-project areas with other relevant data sources.

Steinemann (2001) shows that only making impact assessment mandatory is not sufficient. The generation of alignment alternatives lies at the very core of good planning practice, effective assessments and informed decision making. GIS offers the ability to represent stakeholder concerns and priorities spatially. Spatial tools such as Spatial Multi Criteria Evaluation (SMCE), which can be applied in a trans-scalar manner, are particularly valuable in consensus building across diverse stakeholders and alternative generation across diverse tiers. They help to improve the planning of road infrastructure, by better stakeholder involvement and an impact-based alignment of roads and highways. SMCE techniques, originally developed for areal applications are now being applied to linear applications such as pipeline routing, electricity line routing, network cabling, road routing etc., to generate suitability maps grading the study area into degrees of suitability for the proposed intervention.

5.2 Method

The method to be used in this chapter can be divided into two broad stages. The first stage, based on SEA-like methodologies and techniques described by Fischer (1999, 2006), Therivel (2004), Ward et al. (2005) and Sadler (2010), consists of the tabulation of the planning/assessment tiers, showing their focus, tasks and goals as shown in Table 5.1. Using this, more precise goals are derived from policy documents, and official statements of institutional stakeholders, and opinions expressed by individual stakeholders to be used in the spatial analysis.

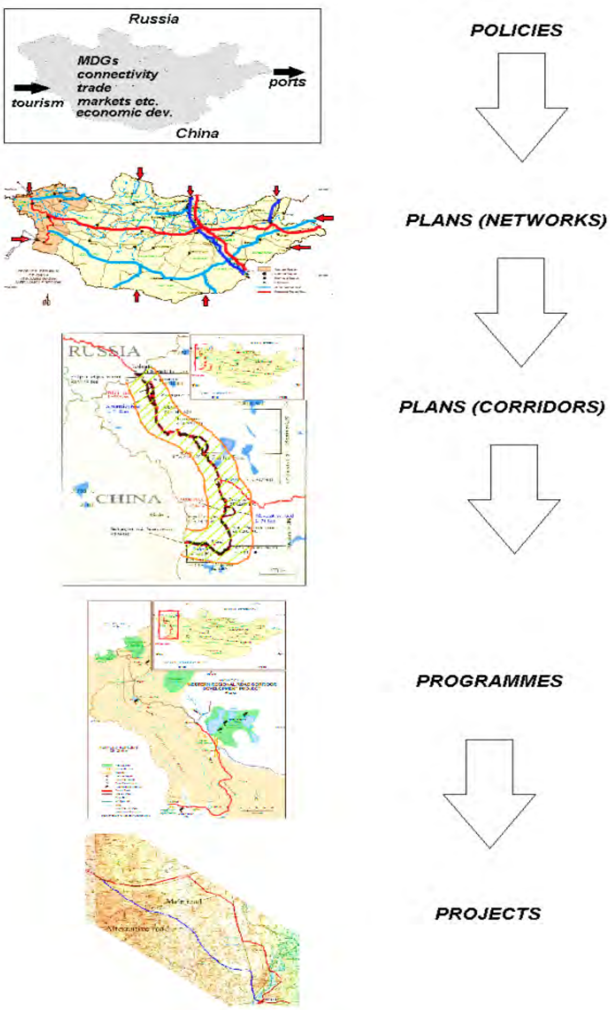

Figure 5.8: The tiered planning process

Once the goals are identified, it becomes possible to fine-tune and verify the stakeholders with interest in the project. The goals can further be operationalised as criteria and spatialised. In this table, 4 tiers are identified – policy/vision, plan (network and corridor), programme and projects. In this chapter, analysis will be conducted up to the corridor planning stage. The following chapter will deal with development of route alternatives within a corridor, and the chapter following that will deal with programmes, prioritization of projects and impacts within projects. Figure 5.8 expresses this graphically by showing how at the policy stage goals and criteria are spatially coarse, sharpening in details (also through map scales) at lower levels. At the highest tier, policies such as fulfillment of the MDGs can be taken up, at the tier below it, network and corridor considerations are taken into account.

Systematic decision-making tier	Focus	Tasks	Goals	Potential Stakeholders (typical)	Types of factors to be considered (indicators)
Vision and policy	Addressing all policy options that might lead to meeting stated policy goals and objectives.	Analysis of the current situation enumerating existing economic, social and environmental objectives and targets and adaptations to transport. Identifying different development scenarios (e.g. economic and spatial) Identifying different policy options that may lead to objectives and targets Evaluating options in the light of scenarios,	<u>International goals.</u> Improve international mobility and market access to: Ports International highways Production centres International Tourism Employment generation (direct & indirect)	1. National governments of Mongolia, Russia, China. 2. Development agencies and development banks. 3. Tourist organisations 4. Distant stakeholders	* Fast, efficient and secure connections to * Regional, national, mining and market centres. * Controllable access. * Int'l Bulk transport capability, with * Multimodal flexibility. * Development of economies, and, * Improvement of social conditions, with * Minimal environmental damage.
		Indicating trade-offs for achieving objectives and targets, Policy assessment, monitoring and adjustments as per actual responses.	<u>National goals</u> Improve access to • Income generation • Basic health care	National, Provincial and local governments of Mongolia. Local producers and service providers (industries and farmers) Local citizens Conservation organisations concerned with policies	Sub-national factors in addition to the above: Access to markets & employment Access to medical facilities Access to schools

			• Basic primary education Improve national mobility Ensure environmental sustainability		Product specific transport: for livestock, crops, ore. Easier travel, Tourism and improving access to cultural heritage. Degradation of environment and protected areas.
			<u>Long-term goals</u> Reducing rural-to-urban migration Increasing capacity to withstand/ respond to: • Natural disasters (particularly *dzud*) • Adverse effects of climate change	National, Provincial and local governments of Mongolia. Farmers, herdsmen and other local citizens.	Creating a nurturing environment for industries, job creation and income generation in rural areas Provision of infrastructure to resist/relieve frequent natural disasters. Enabling better access to relief mechanisms during times of natural calamities such as floods, dzud, drought.
Plans	<u>Network plans</u> • National or regional infrastructure development options leading to specific transport development choices	<u>Network assessment</u>; • Analysis of current situation identifying – intermodal – development options according to needs identified in policies	Rail corridors Highway corridors	National and provincial governments Transport companies and users	Technical and financial feasibility. Multimodality, through coordinated development of existing and planned rail and road networks

		• assessing impacts on different options to achieve objectives and targets. • indication of possible trade-offs • feedback to policies • monitoring actual developments	Ecological corridors Terminals: • Intermodal trans-shipment • Airports • Border posts	Conservation organisations concerned with national and regional projects	ecological networks (using environmentally sensitive zones including protected areas) identification and development of facillities at nodes reduction of technical delays at border posts (for e.g. rail guage change)
	<u>Corridor plans</u> Identification and spatial locations of corridors between nodes specified in network planning	<u>Corridor assessment</u> • Analysis of current situation • Identification of potential impacts (advantages and disadvantages) within corridor • Identification of stakeholders, visions, concerns and priorities	• avoidance of negative impacts to greatest extent possible • development of alternatives based on visions from upper tiers taking into account biophysical, social, economic, technical and technological factors • feedback to policies and networks	Provincial and local governments Funding agencies and banks Conservation organisations concerned with landscape fragmentation and regional projects Producers (prospective and existing) and Users	Proximity to other modes, land use being affected, environmental sensitivity, construction and operation costs, financial repayability, biophysical and socio-economic advantages
Programmes	Identify priority projects: • in each network sector,	<u>Programme assessment</u> • Analysis using multi-criteria analysis, cost benefit analysis,	• concrete impact assessment translated into factors and objectives • avoidance of negative impacts to greatest extent	Provincial and local governments Funding agencies and banks	Proximity to network nodes, land use being affected, environmental sensitivity, construction and operation costs, financial repayability, biophysical and socio-

	• in each corridor	etc. •Monitoring actual developments and regularly adjusting them	possible • development of alternatives based on visions from upper tiers taking into account biophysical, social, economic, technical and technological factors • feedback to policies and plans	Conservation bodies concerned with specific species or zones, regional projects Local industries (prospective and existing), Land-losers, future users	economic advantages and disadvantages
Projects	Project design	<u>Project EIA</u>	Optimise project design in terms of programme objectives and targets.	Provincial and local governments and politicians	Number of affected land-losers, land use being affected, Costs and benefits, Mitigation measures – design and cost. Design, construction and operation criteria and costs.
	Identify priority sections	Mitigate and compensate impacts that cannot be avoided.	Identify focal species, locate and design mitigation measures	Proponents, construction companies, engineering & project consultants	
	Minimise negative construction impacts. Procedural optimisation: expedite execution, maximise financial benefits, technical design, technology and contract management.	Manage local stakeholders Monitor actual developments.	Land acquisition, identification and conciliation of key local stakeholders' concerns Monitor impacts : baseline, during construction and post construction	Conservation forums concerned with local ecological losses Funding agencies and banks	

Table 5.1: Strategic tiered planning for the Millennium Highway/AH32 corridor (Extended version).

5.2.1 Identification of important factors and priorities

Using Table 5.1 several factors that needed to be considered in the planning at each tier can be identified. As is seen in it, the uppermost tier carries broad goals such as achievement of the MDGs, international cooperation and trade, increasing socio-economic resilience to climate change and natural calamities.

The MDGs are however, not criteria that are 'easy' to spatialise for analysis, but we do know how they are relevant. For example, sheep-herders get much 40% lower prices for their wool produce if the wool is dusty and soiled from travelling long distances on dirt-roads (World Bank, 1999); maternal mortality can be seriously affected if medical centres can only be reached by travelling long distances over rutted, washboarded roads (Sundari, 1992); rural primary school dropout rates are higher when schools are difficult to reach, especially when the families that the children belong to are besieged by poverty; child-health rates are worse in regions with poorer transport (Fay et al., 2005). Accordingly the following objectives are identified as relevant to the highway planning in the Mongolian context[14]:

1. Reduce poverty by improving accessibility to markets and employment centres (addressing MDG-1),
2. Improve access to universal primary education (address MDG-2),
3. Reduce child mortality rates (MDG-4) and,
4. Improve maternal health (MDG-5),
5. Without encouraging the spread of HIV/AIDS and other infectious diseases (MDG-6),
6. Ensuring the design is environmentally sustainable (MDG-7), while
7. Developing global partnerships for development (MDG-8).

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[14] Highways can help to achieve these goals (if properly planned and aligned), although, this must necessarily be in combination with other tools as well. For example, for the goal of improving accessibility to healthcare, the creation and staffing of medical centres must go hand in hand with creating better roads to reach them. It can also be pointed out that most of these goals are interlinked to each other as well. However highways must generally be the precursor to the other initiatives.

Furthermore, despite the fact that the highway will form part of the international network, the onus of repaying the cost of constructing it will be borne solely by the Mongolian government, hence, as it is stated in the government's transport strategy, techno-commercial viability is as important as social connectivity and ecological protection. Hence several basic techno-commercial criteria were identified though personal non-structured interviews with experts and organizational stakeholders (Keshkamat, 2008a, Keshkamat, 2008b, Keshkamat, 2008c, Keshkamat, 2008d, Keshkamat, 2008e, Keshkamat, 2008f, Keshkamat, 2008g). Mongolian government policies and plans, UNESCAP priority criteria, ADB and World Bank guidelines were also reviewed and used to draw criteria of relevance to the alignment process. These are, for example:

1. Slope,
2. Current Traffic density
3. Land-use that will be affected
4. Population that will be potential users/beneficiaries
5. Depth of permafrost
6. Length and number of bridges needed etc.
7. Border posts
8. Proximity to sea ports

A full list of criteria, segregated into theme-groups based on the nature of their action, is listed in Table 5.2. The themes are envisaged as: transport, ecology, social, economy, and construction. Table 5.2 shows the various factors proposed as input criteria, grouped into themes, and the details of their operationalization.

It is needed to mention here that this research did not have an official mandate and therefore does not reflect the official views of the above mentioned organisations, but the cooperative professional and personal views of the interviewed officials, along with this author's interpretation of the various policy and plan documents that were reviewed. The outputs will also be reviewed by them for possibility of use. However, as mentioned in Chapter 1, realistically, highway alignment processes are strongly influenced by political rationalities. However, by including criteria of political and social rationality along with economic, technical, legal and ecological rationalities, the possibility of a political acceptance of the outputs is increased.

theme	criteria	type	Data type	Pre-processing
Transport	Slope	Spatial cost	Raster	Generated from DEM
	Traffic density	Spatial benefit	Polygon	Rasterize
	Aspect (NW)		Raster	Generated from DEM
Ecology	Strictly protected areas	Spatial constraint	Polygon	Rasterize
	forest	Spatial cost	Polygon	Rasterize
	Other protected areas	Spatial cost	Polygon	Rasterize
	Water bodies	Spatial cost	Line\Polygon	Rasterize
Social	Population density	Spatial benefit	Polygon	Rasterize
	Poverty	Spatial benefit	Polygon	Rasterize
	Health care facilities	Spatial benefit	Point	IDW interpolation
	basic education	Spatial benefit	Point	IDW interpolation
	Agricultural area	Spatial cost	Polygon	Rasterize
Economy	Proximity to economic centres	Spatial cost	Point	IDW interpolation
	Proximity to border-post	Spatial cost	Point	Distance calculation
	Proximity to potential economic centres	Spatial cost	Point	Distance calculation
	Agricultural yield (county-wise)	Spatial benefit	Polygon	rasterize
	Livestock yield (county-wise)	Spatial benefit	Polygon	rasterize
	Proximity to Touristic attractions	Spatial cost	Points	Distance calculation
Construction cost	Intersections with perennial and seasonal water bodies	Spatial cost	Intersection of Polygon and line	Rasterise
	Permafrost	Spatial cost	Polygon	Rasterise

Table 5.2: Criteria considered in the planning and their operationalisation details.

Based on these themes and criteria, the criteria were spatialised into a GIS environment. All the rasters were either generated, or resampled, to the same resolution of 2km. Slope and aspect maps were derived from the Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM) of Jarvis et al. (2008).

Annual Average Daily Traffic (AADT) enumeration charts for 2008 obtained from the RSRC (2008) were spatialised by allocating vehicle counts from the tables to the road vector map and then rasterised. Data of land cover and protected areas were sourced from the National Geoinformation Centre for Natural Resource Management (NGIC) project (2008) in Mongolia and rasterized.

In the social theme, data of population density, health care and basic education facilities were digitized from National Atlas of Mongolia (2009). As represented in the National Atlas of Mongolia, hospital and school capacity are classified and coded from one to seven. For example, lowest code of health care, 1 means a capacity of less than 20 beds in the hospital while highest code 7 means a capacity of more than 250 beds in the hospital. Bed capacity is generally known as a direct indicator of capability (expertise and facilities) available. Similarly, in education facilities, the lowest code 1 means there are less than 500 pupils at schools in one county, while code 7 means there is more than 185000 pupils at schools in for example Ulaanbaatar. These codes were given to the centroid of the population centre and interpolated using the Inversed Distance Weighting (IDW) interpolation technique. This technique, usually used in interpolating meteorological data (for example) creates what we term an '*importance weighted distance raster*'. For example, regional health centres have far more facilities than county health centres, so residents of neighboring counties tend to go there for bigger ailments. The IDW form of interpolation was particularly chosen because the surface being interpolated should be more strongly related to the distance from the nearest point.

The report of the Mongolian Census Based Poverty Map (Coulombe and Otter, 2009) was used in spatialising the poverty distribution throughout the country county-wise and was then rasterized for the analysis. For criteria in the Economy theme, Euclidean distance rasters were generated from vector maps of the province centres, county centres, border post, potential economic centres (such as those with known mining or industrial potential) and tourist attractions. Data of agricultural yield and number of livestock of each county in 2007 was also spatialized from the National Atlas of Mongolia and rasterized for the analysis. In construction theme, bridges which required were identified by intersecting the dataset of perennial and seasonal water bodies with roads and rasterized. The permafrost map from the National Atlas of Mongolia was also rasterized for the analysis.

5.2.2 Assessing locational suitability

Nijkamp (1990) and Vreeker (2002) state that multicriteria evaluation offers perhaps the best way to incorporate varied criteria and different perspectives in a manner that can support transport decisions based on alternatives derived through stakeholder consensus. Hence, once the criteria were operationlised, they were applied as input to a spatial multicriteria assessment (SMCA) process in ILWIS.

In a SMCA, criteria are usually classified into costs, benefits or constraints, based on the type of impact. A spatial benefit is defined as a criterion that contributes positively to the output; the higher the value, the better it is. A spatial cost is defined as a criterion that contributes negatively to the output; the lower the value, the better it is. A spatial constraint is accordingly defined as a criterion that determines which areas in the final output map are considered as absolutely not suitable for the proposed development. Poor performance of a criterion can be compensated by good performance of another criterion, which can lead to a good overall 'suitability' in the cumulative suitability map. As opposed to factors, poor performance of a constraint cannot be compensated by good performance of another factor or constraint. These areas will always obtain null value for that pixel in the final output. Criteria that represent legally protected - or otherwise unavailable - areas are usually made constraints.

The geo-spatial datasets representing the different criteria (costs, benefits and constraints) described above are combined to prepare suitability surfaces for different policy visions, using weights derived from policy visions or presentations by policy-makers and decision makers at official forums such as the UNESCAP Regional Workshop on Upgrading of the Asian Highway Priority Routes (19-21 June 2007, Bangkok) and (Onon, 2010), and also through personal interviews with officials in charge with the Millennium Road portfolio at the World Bank – Mongolia (Keshkamat, 2008c), Asian Development Bank – Mongolia (Keshkamat, 2008g), Millennium Challenge Corporation (Keshkamat, 2008a), Road Supervision and Research Centre and Department of Roads of the Government of Mongolia (Keshkamat, 2008f, Keshkamat, 2008e) and their appointed planning consultants (Keshkamat, 2008d) and assessment consultants (Keshkamat, 2008b). In addition interviews were also conducted with the United Nations Development Programme (UNDP) Mongolia, World Wildlife Fund, the Ministry of Nature and Environment and several provincial government representatives along an east-west trajectory.

Five visions were proposed in this analysis based on the perspectives encountered in the personal interviews. Each of these visions generates a suitability map. The visions are:

1. Social Vision – social factors are paramount.
2. Economy vision – economic growth and international trade are first.
3. Construction vision - techno-commercial criteria should guide design.
4. Ecology Vision – Ecological considerations are most important in the design.
5. Equal or Neutral vision – a vision which considers all themes as equal.

Themes	Visions				
	Equal vision	**Social vision**	**Ecology vision**	**Economy vision**	**Constr. vision**
Transport efficiency	0.20	0.26	0.26	0.26	0.26
Social impact and safety	0.20	0.46	0.16	0.09	0.09
Economic costs and benefits	0.20	0.16	0.09	0.46	0.16
Ecology	0.20	0.09	0.46	0.04	0.04
Construction costs	0.20	0.04	0.04	0.16	0.46

Table 5.3: Different visions, themes and weights used in this study

The visions are used to derive the weights for the themes (Table 5.3) under which the criteria are grouped using expected value method (Janssen, 1992, Saaty, 1980, Uran and Janssen, 2003). With the assignment of weights the importance of a theme for the purpose of the corridor alignment is emphasized. Within the theme itself the various criteria are similarly weighted against each other to emphasize their importance within the theme. In these planning tiers, the importance of criteria against each other is guided by national policies and strategies, or as decided by institutional representatives. It may be argued that weights attributed at this level are highly subjective. However exponents such as (Wilkins, 2003) have countered that as per the World Summit on Sustainable Development (WSSD) held in Johannesburg which sought to foster the implementation of the sustainable development objectives set out in the 1992 Rio Earth Summit's Agenda 21, the legitimacy of assessments, partly lies in the subjective bases into which they are rooted.

As mentioned in section 3.4, standardisation of criteria is the juncture at which expert inputs are applied to the criteria input maps to assign values between 0 (not suitable) and 1 (highly suitable) to the rasters' native values. Table 5.4 shows the standardisation parameters which were applied to the datasets within this analysis. The type of standardisation and break values were derived from personal interviews with professionals, local experts and own professional knowledge.

Criteria	Influence	Type of standardisation	Break Values
Slope	Cost	Goal	0, 9
Aspect	Cost	Convex Goal	0, 180
Traffic Density	Benefit	Goal	0,max
Poverty	Benefit	Goal	0, 5km
Population density	Benefit	Goal	0,max
Health Care	Benefit	Goal	0,max
Basic education	Benefit	Goal	0,max
Agricultural areas	Benefit	Attr	crop
Agricultural production	Benefit	Goal	0, 2km
Livestock	Benefit	Goal	0, max
Tourist attractions	Benefit	Goal	0, 200 km
Economic centres	Cost	Goal	0, 200 km
Border posts	Cost	Goal	0, 400km
Expected economic centres	Cost	Interval	0, 200 km
Other protected areas	Cost	Attribute	Other
Forests	Cost	Attribute	forest
Strictly protected areas	Cost	Attribute	SPA
Water bodies: lakes	Cost	Goal	0, max
Water bodies: Rivers	Cost	Goal	0, max
Permafrost	Cost	Goal	0, max
Water crossing: lake	Cost	Convex Goal	0, max
Water crossing: Rivers	Cost	Goal	0, 4 km
Water crossing: stream	Cost	Goal	0, 2km

Table 5.4: Table showing standardisation parameters of the criteria.

Once the various input layers are standardized and criteria weighted, the SMCA 'criteria tree' in ILWIS was used to generate the combined suitability maps for each vision. Figure 5.9 shows the example of the Social vision criteria tree. For each vision there is such a tree, and a corresponding combined suitability map generated.

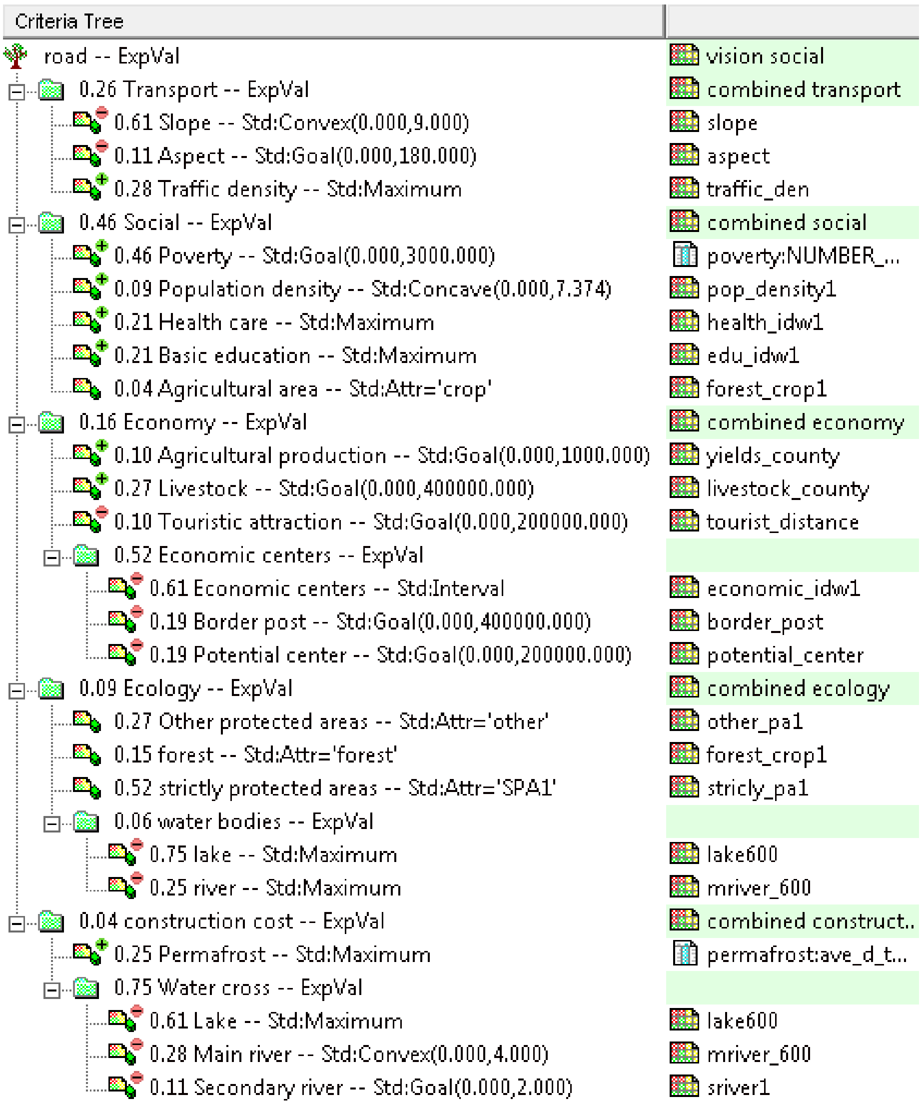


Figure 5.9: SMCA criteria (social vision)

The combined suitability map provides a continuous geographic surface showing the suitability of each pixel (2km x 2km on the ground) across the entire study area (Mongolia) for the routing of the highway corridor. This type of continuous surface is similar to a friction map or an impedance map

(Grossardt et al., 2001, Yusof and Baban, 2004). The values of all pixels (cells) in this raster lie between 0 and 1 depending on their suitability to the location of the highway in that pixel. 1 represents highest suitability, and 0 means that the area covered by that pixel is totally unsuitable.

5.2.3 Generation of corridor alignments

Using suitability maps generated from SMCA analysis, impedance maps of each vision were generated by reversing those suitability maps, i.e. subtracting all values of the raster from 1, thereby converting the map values into "unsuitability" values or resistance, or in other words, impedance. Impedance maps were used for Least Cost Path analysis, to generate optimal routes for each vision having least 'total impedance' and therefore the most suitability for the full route. Least Cost Path analysis was conducted in ArcGIS using cost-distance functions.

The Least Cost Path analysis determines the path from one or more destination point to one or more sources. After creating cost distance maps, which determines the shortest weighted distance (or accumulated travel cost) from each cell to the nearest cell in the set of source cells, least cost path from a chosen destination to our source points is generated. Together with cost distance maps, the so-called 'backlink raster' is also created using the Cost-direction to retrace the least-costly route from the destination to the source over the cost distance surface.

The cost distance functions (also known as cost-weighted distance) modify Euclidean distance by equating distance with a cost factor, which is the cost to travel through any given cell. For example, it may be shorter to climb over the mountain to the destination, but it is faster to walk around it. In this case, the cost value is delivered from the impedance surface. The cost allocation function identifies the nearest (or least costly) source cell based on accumulated travel cost. The cost direction function provides a road map, identifying the route to take from any cell, along the least cost path, back to the nearest source. The cost distance analysis guarantees delineation of the 'cheapest' route (relative to the cost units defined by the original cost raster).

As mentioned before, the Millennium Road must pass through certain destinations: These are Hovd, Ulaanbaatar, Ondorhaan. The last stop, i.e. the eastern most border-crossing has been and continues to be a subject of dispute and wide agitation (UNESCAP, 2007, Wildlife Conservation Society, 2005, Zahler et al., 2007). The originally planned route - Ondorhaan to Sumber is the subject of the most criticism and two alternative destination border-crossings of Havirga and Bichigt are in consideration. Hence they were also added to this study for route comparison.

Since, total highway has to go through several destination points Least Cost Path analysis was done with 2 steps. In the first step, Ulaanbaatar is defined as source and Hovd and Ondorhaan are defined as destinations. Thus, in first step, optimal route connecting Hovd with Ondorhaan via Ulaanbaatar was generated (Step 1 as shown in Figure 5.10).

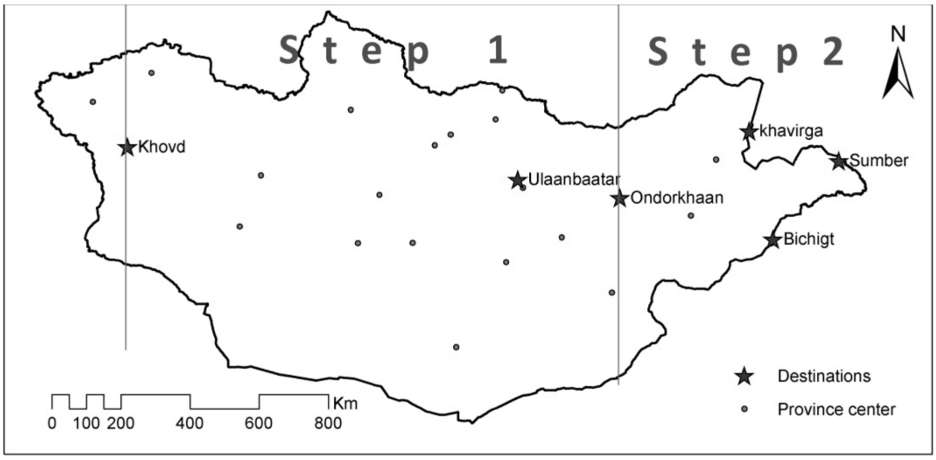


Figure 5.10: Steps in the Least Cost path generation process

In the second step, Ondorhaan was defined as source and Sumber, Havirga, and Bichigt are defined as destinations. From this step, optimal routes connecting Ondorhaan to Sumber, Havirga, and Bichigt were generated and merged with the outputs of the first step. After the route corridors were generated, total impedances of each route and each sub-alternative were calculated and compared qualitatively on a map, and quantitatively.

5.3 Results

Results of the process described above are shown in this section. The suitability maps generated for each of the five visions are shown in Figure 5.11, Figure 5.12, Figure 5.13, Figure 5.14 and Figure 5.15. These are only intermediate products in the generation of the corridor routing, but are also useful to see how the different policy visions can affect the implementation of the country's transportation strategy. The maps' symbology is graded between red and green. Red indicates high unsuitability, green high suitability and other shades in between represent various degrees of suitability.

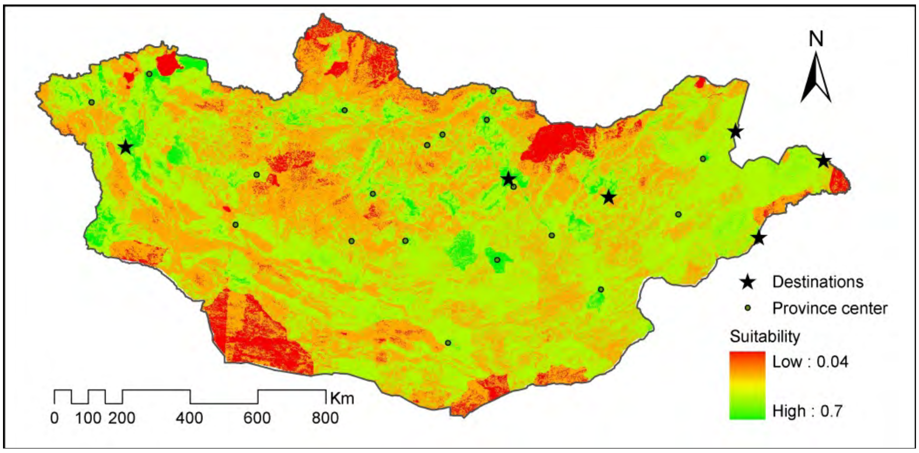


Figure 5.11: Equal Vision

The lowered suitability of certain areas due to their being protected areas is seen in this map. However because they are tempered by the relatively equal importance of other criteria they seldom become completely unsuitable.

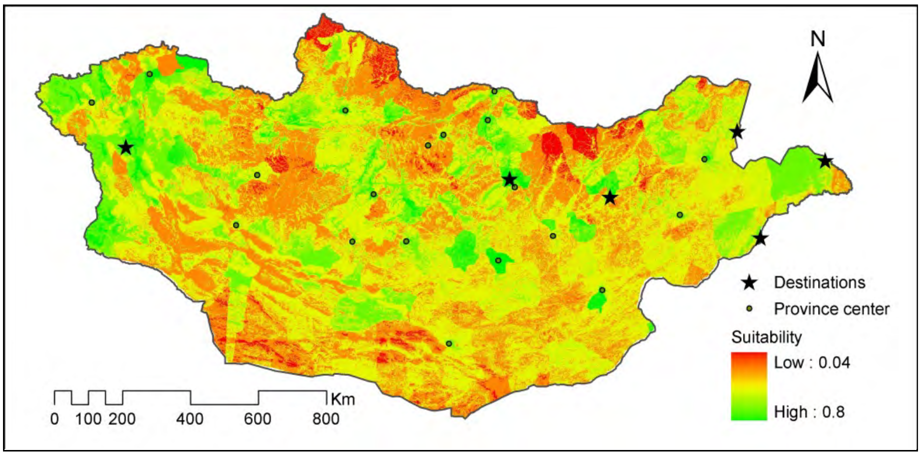


Figure 5.12: Social Vision

Compared to the previous map, the social vision map shows that most of the country is suitable for the highway alignment, some areas are more suitable than others, but there is almost no area that is unsuitable. This unusual situation can be attributed to the scarce population distribution.

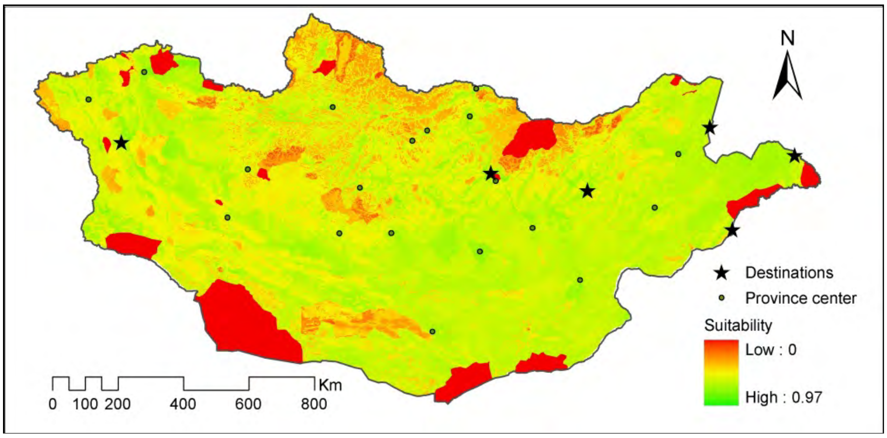


Figure 5.13: Ecology Vision

The suitability map as per the ecology vision shows that most of the country is suitable, except the protected areas which become classified as unsuitable. However, since most of these are on the peripheries of the country, it doesn't particularly pose a problem to highway alignment, except in the Nomrog strictly protected area and the Dariganga National park in the extreme east. However the other eco-sensitive zones in the country are classified as lower suitability, and not unsuitable.

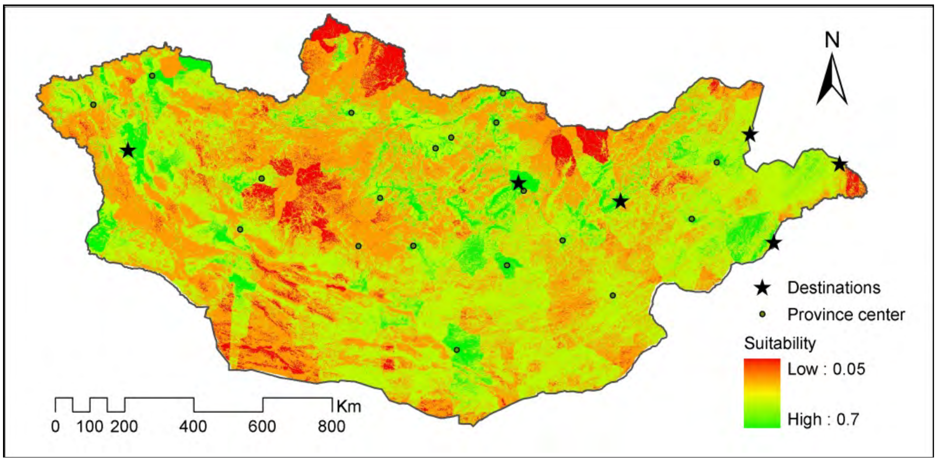


Figure 5.14: Economy Vision

From the viewpoint of the economy vision also, most of the country is suitable, although some areas, in high mountain ranges, are unsuitable, probably in terms of cost to traverse them. The construction vision too shows a view similar to the economy vision.

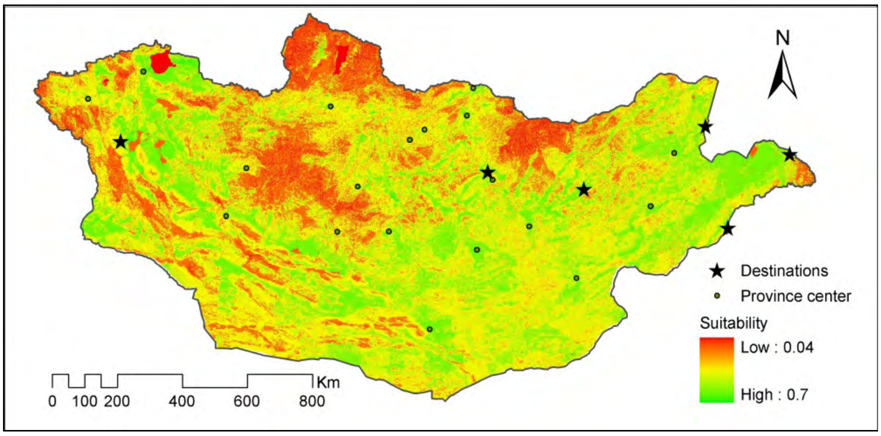


Figure 5.15: Construction Vision

These descriptions are however highly qualitative, mainly because such an assessment would be based more on the symbology (colour gradient) used, rather than an objective interpretation. The cost-path technique however is not hindered by the symbology subjectivity and uses the real values of the pixels. The least cost paths for each vision are shown in Figure 5.16, Figure 5.17,

Figure 5.18, Figure 5.19 and Figure 5.20 (overlaid on the respective suitability raster for reference). It should be noted that although the routes are shown as a line, they do in fact have a width of 2 km, which is the raster resolution.

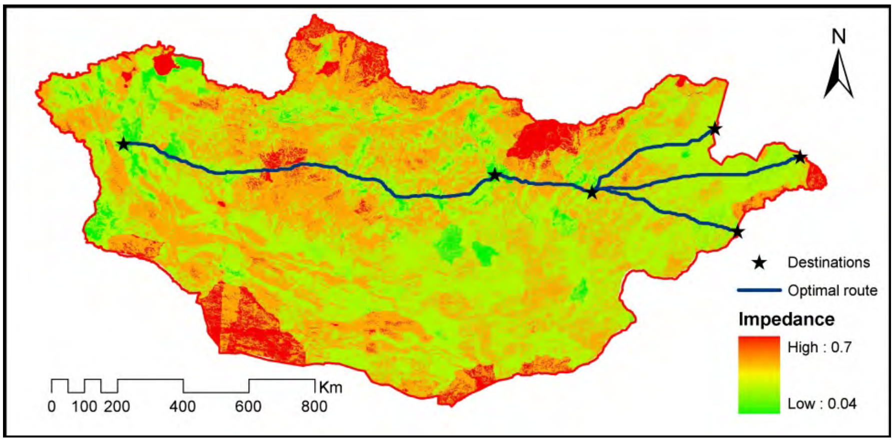


Figure 5.16: Equal vision route

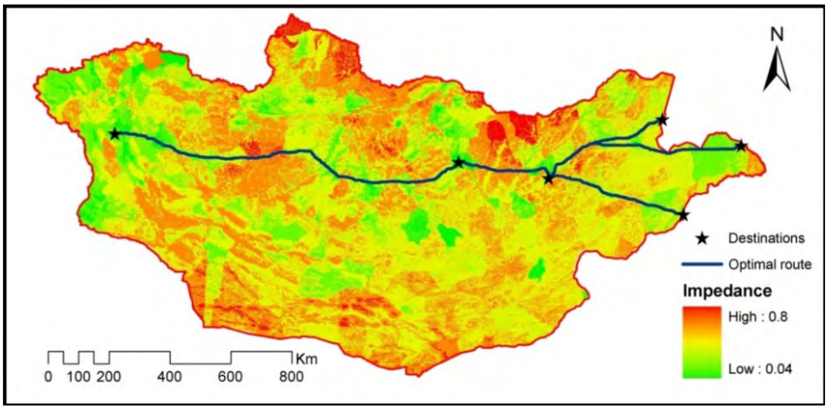


Figure 5.17: Social vision route

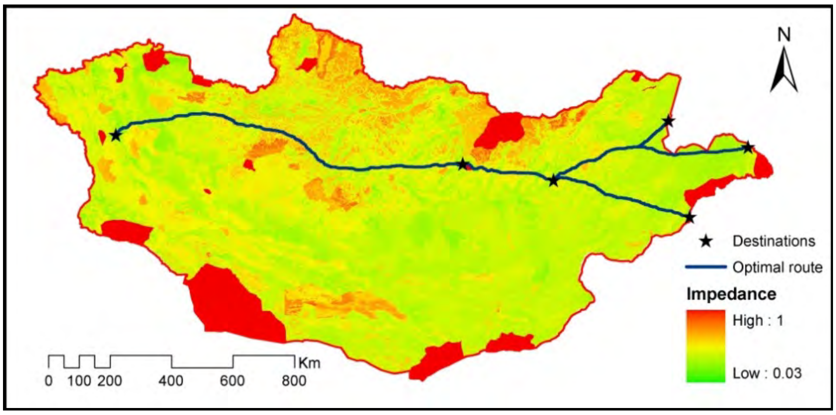


Figure 5.18: Ecology vision route

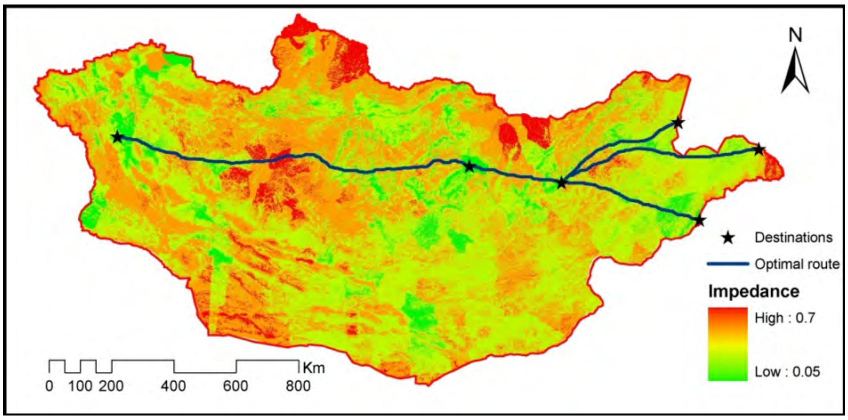


Figure 5.19: Economy vision route

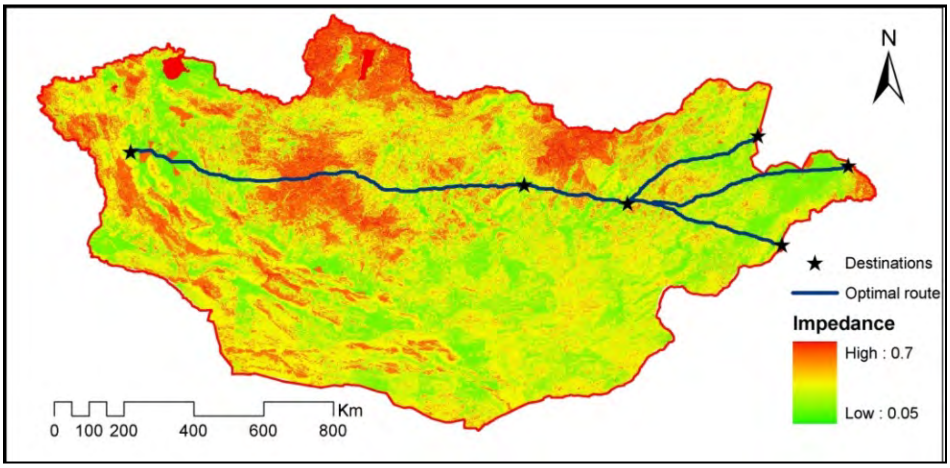


Figure 5.20: Construction vision route

The detail discussion regarding the 5 routes generated using these visions will be discussed in detail in the section 5.4.1. However prior to the discussion, a quantitative assessment is conducted by extracting the net impedance value of each route. The routes are overlaid in the same map (Figure 5.21) so that a visual, qualitative examination may be conducted.

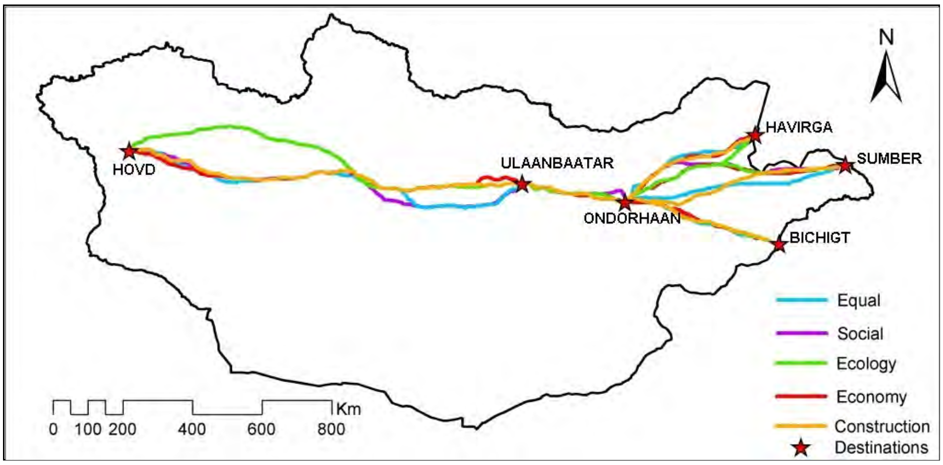


Figure 5.21: Comparing all corridor routes (segment-wise).

The impedance of each route is tabulated in Table 5.5, so that they may be compared against each other in a quantitatively.

Khovd - Undurhaan	equal vision	social vision	ecology vision	economy vision	construction vision
equal route	685.7	1064.2	746.6	932.4	636.5
social route	943.3	1366.9	997.5	1228.5	864.3
ecology route	726.4	1090.6	684.8	944.5	621.8
economy route	722.9	1073.6	734.1	889.4	621.7
construction route	721.0	1076.0	734.1	924.7	585.9
Undurhaan - Khavirga	equal vision	social vision	ecology vision	economy vision	construction vision
equal route	202.3	309.1	193.8	267.8	164.7
social route	207.3	296.7	200.8	263.0	158.2
ecology route	209.2	308.4	184.0	265.5	166.9
economy route	207.3	306.8	196.4	253.1	158.3
construction route	214.2	314.8	209.1	274.6	155.9
Uundurhaan - Sumber	equal vision	social vision	ecology vision	economy vision	construction vision
equal route	315.9	501.7	298.0	422.7	260.7
social route	325.8	472.7	308.0	423.6	248.3
ecology route	325.2	480.3	283.6	417.3	247.8
economy route	330.9	491.6	298.7	411.6	254.6
construction route	331.9	507.3	296.2	433.8	238.4
Undurhaan - Bichigt	equal vision	social vision	ecology vision	economy vision	construction vision
equal route	217.3	348.7	210.6	282.3	183.1
social route	230.8	344.5	212.9	287.2	179.3
ecology route	223.7	343.8	206.1	279.5	175.3
economy route	228.5	350.7	213.2	274.6	181.8
construction route	238.3	359.1	218.3	295.3	178.2

Table 5.5: Quantitatively comparing all corridor route impedances (segment-wise).

5.4 Discussion

This section will discuss the results and their geographical implications in detail. After the discussion on the results, the significance of this method to policy and planning will also be deliberated.

5.4.1 Analysis of the alternatives and their implications

In Figure 5.21 all the routes could be compared qualitatively. Table 5.5 allowed a (quasi-)quantitative comparison of the routes within a vision based on their impedances. For example, if the social vision were chosen as the vision to follow on the Hovd to Ondorhaan route, the route shown as the equal route would offer the best suitability, closely followed by the route shown as the social route. Similarly, the impedance figures can also be used to choose the best route within a vision. For example, for the section from Ondorhaan to the eastern border, from the viewpoint of economy, the economy route of Ondorhaan-Havirga provides the alternative that will give highest value. On the other hand, even if a social vision was chosen as important, the Ondorhaan-Havirga route gives best value, with some small alterations (i.e. the social route in the social vision). Construction-wise, ecology-wise and even if all themes are equal the Ondorhaan-Havirga route offers lowest impedance values across the board, i.e. the most suitable routes.

This feature of comparing routes using impedance values offers a very valuable insight into the comparison of alternatives, based on the same original framework of criteria and perspectives, and thus encourages consistency in decision support and decision making. It also allows transparency with respect to stakeholders as well as auditors. Of course, politicians are wary of excessive transparency, however they still stand to gain by using the method demonstrated here because it can take into account all concerns and priorities of their electorate interests in a demonstrable manner. Stakeholder satisfaction would see a drastic increase and therefore confidence in the decision making processes. Thus the impedances offer an objective way of assessing and comparing routes. However, it is also advisable not to just take the numbers routes at face-value, but also to compare the routes qualitatively.

Between Hovd and Ulaanbaatar, the corridor trajectories delivered by the analysis provide an interesting insight - Since the planning of the Millennium Road/AH32 began, it has been debated whether the highway should take the ‘northern route’ or the ‘southern route’ (as they are so called in colloquial and guidebook parlance), which are corridors currently used by most people travelling to and from the capital to the western cities of Hovd and BayanOlgiiy (Figure 5.22). The ‘northern route’ consists of the corridor Ulaanbaatar-Darhan-Erdenet-Bulgan-Moron-Ulaangom-Bayan Olgiiy/Hovd, shown in red, whereas the southern route consisted of Ulaanbaatar- Arvayheer-Bayanhongor-Altai-Manhaan-Hovd/BayanOlgiiy, shown in blue. Only since mid-2008 an ambiguous ‘middle route’ begins to appear in documents, with different documents describing it differently. Our analysis showed that regardless of the policy vision chosen, the so-called ‘middle-route’ is indeed the best. Except for a portion of the route generated by the ecology vision basis (Figure 5.18), all other 4 visions' routes run exactly the same route. It will be seen that if this portion were made to comply with the other routes, it may not be the most optimal route of the vision, but the effect would still not be critically deleterious to the ecology.

Figure 5.22: Reference map for places mentioned in discussion (Source: Google Maps,(2011f))

In highway alignment planning, it is known to be extremely rare that one route satisfies all perspectives, some of which even have contradictory goals. This route appears to take advantage of a small break in the otherwise continuous and high Hangayn Nuruu mountain range. If the implications of this corridor alignment are examined, it is seen that it could serve locations the northern and southern routes equally through herring-bone type network, thus enabling the most balanced development for the western half of the country, compared to either a southern or northern route, which would concentrate development to the south or north respectively. It passes through two major provincial centres, and in easily motorable proximity of five others.

Between Ulaanbaatar and Ondorhaan, again all the generated routes follow quasi similar alignments. However, in this section, it is not such a surprising outcome – this section parallel to a mountain range alongside which the Herlen, a main river, also flows. Further, since 2006 there has been sporadic development of the road stretches from Ulaanbaatar to Ondorhaan. It would be preferable, and following the UNESCAP AH mandate, to use these stretches.

Figure 5.23: Reference map for place names used in discussion of alternatives (Source: Google Maps,(2011f)).

The section east of Ondorhaan (Figure 5.23) is an important issue that calls for scientific assessment and support to decision making. It has as mentioned before also faced debate and agitation due to contrasting views and reviews. Other than the criteria of the Nomrog strictly protected area, much of the local and national debate regarding the alignment of this section has centered around the distance to sea ports, nationality of sea ports, potential of rail connectivity, border posts, mineral rich zones and connectivity to main populated centres (Choibalsan, Baruun Urt – either, both or neither).

The UNESCAP's widely acclaimed Time/Cost-Distance methodology (Baku, 2008, Findlay, 2009, Pomfret, 2011, Qian, 2009, Sourdin and Pomfret, 2009) also gives priority to these aspects in the Asian Highway network, thus imparting credibility to this factor. In order to provide salient support to the decision making, our analysis included these concerns as well. Our analysis showed that if Bichigt border station is taken as the point of crossing, all alternatives will again follow the same route, that through the provincial centre Baruun Urt, which is also a major industrial and aluminum mining township. A continuation of this road on the Chinese side would reduce the distance to Tianjin port by about 100km and also create opportunities to use the Chinese port of Dalian. However, such a network link (Bichigt to Tianjin) would duplicate the utility of the AH3 from Zamyn Uud to Tianjin, which is actually a more efficient and environmentally sensible alternative because it bundles the rail and road links in one corridor. The creation of such a link would also split the viability of the AH3 corridor; hence the Chinese government too is not likely to support such a development. Thus this corridor alternative cannot be the preferred alternative.

On the other hand, one of the stated political objectives of the Mongolian government is to explore and create new trade opportunities by reducing the monopoly that China has on transit traffic to Mongolia. The other two alternatives – Sumber and Havirga are better placed to address this objective. Furthermore China also stands to gain by the development of road links from either of these two crossings as such a highway link would also pass through three main Chinese cities- Qiqihar, Daquing and Harbin.

On the Mongolian side, of the various route alternatives, all except the equal vision and construction vision route pass through the eastern most city of

Choibalsan, which is also the regional centre for Eastern Mongolia. As a regional centre, it is a city with industry, medical and educational infrastructure and a population of about 40,000 people. It is the fourth largest city in Mongolia, and before democratisation in 1992, had been a major economic hub of the country. It saw a steady decline following democratisation. If it were to receive a boost through stronger national and international connectivity, the capabilities of the dormant infrastructure and population could be easily revived and the city could be redeveloped as an economic centre. One of its strongest advantages is also the existing rail connection from Choibalsan to Eerentsav, the border post with Russia. Passing the highway through Choibalsan would thus create enormous employment potential for the local people, transport efficiency and multimodality as well as fulfill social goals. Since these are the flattest lands in the country, with no known soil conditions, modifying the construction vision route by a few tens of kilometers is not likely to affect technical viability noticeably, yet the commercial viability would be many-fold higher. There is therefore a strong case for the highway to be aligned through Choibalsan.

East of Choibalsan two possibilities are offered for alignment – the border post of Havirga or the border post of Sumber. These two alternatives are compared below against various criteria. Based on the reasoning shown in it, *prima facie* it appears that the crossing the highway at the border post of Havirga is the better alternative, even though each alternative has its pros and cons (Table 5.6).

Criterion	At Havirga	At Sumber
International	Close to Russian border	Far from Russian border
Multimodality (nearest rail hub)	300km to Hulunber (China) - a rail transshipment hub	500km to Qiqihar (China) - a rail transshipment hub
Nearest international highway	• 40km to S203 provincial Chinese road • 80km to proposed AH6	30km to S203 provincial Chinese road.
Sea port access	1500km to Vladivostok of which 900km by existing highways	1200km to Vladivostok of which 600km by existing highways
Economic	Currently used by Mongolians to trade with Hulunber city. May be useful with future uranium mines.	Future regional road which can also be used to serve border areas and oil rigs
Temporal	Currently known to turn muddy in some stretches during snow melt (June-July) on Herlen river	Expected to turn muddy in some stretches near the border during snow melt (June-July) on Halhin river
Environmental	No ecologically sensitive area affected	The highly sensitive Nomrog Strictly Protected Area is likely to be affected
	dirt track propagation seen due to current use will be addressed	No dirt track propagation observed yet.
Social	Close to Hulunber city in China and currently used by almost all people of Dornod and adjoining provinces.	Sumber is usually used by local people of the Halhin Gol area.
	Crosses border within short distance of Choibalsan	Runs parallel to sensitive border for 400km, thus creating opportunity for toll and border leakages
Techno-commercial • Distance within Mongolia from Choibalsan (i.e. cost to Mongolian government)	~150km	~425km
• Ancillary structures	Culverts over tributaries of the Herlen.	Major mitigation structures at Nomrog wildlife sanctuary Major bridge on Halhin river.

Table 5.6: Comparing border crossing at Sumber vs Havirga.

5.4.2 Policy significance and utility

By taking account of criteria that were hitherto considered as soft variables that cannot be directly addressed, this chapter has shown that not only can they be addressed, but also that highways can be used as one of the institutional tools to achieve the MDGs. This study proves that the outputs generated by doing so need not be vague vacuous ideas, but practical results that can be readily implemented.

The method and case study demonstrated in this chapter carries significance and utility to highway planning at a broad strategic level of planning. At this early stage of the planning a wide gamut of options and alternatives is available to decision makers, planners and stakeholders. It is at this stage that it is imperative to make decisions that would enable lower levels with sufficient choice to plan effective projects. If systematically carried though, this technique would deliver outcomes that get progressively better at lower levels. In doing so, this method demonstrated the multi-scalar viability of this planning approach. The case-study was carried out at 3 levels of analysis with SMCA, which by itself is amenable to use at any scale, and with data resolution sufficient for the expression of broad issues at the large sub-continental extent.

To assess the institutional capacities needed for such a rigorous planning, important portions of the data used in this method were especially derived from free and open source remote sensing data repositories. The information needed to carry such a thorough analysis is readily and freely available and can be used without requirement for extraordinary institutional capabilities. However, the awareness of the availability and the potential of such data and techniques in good quality planning should be increased.

5.4.3 Elaboration of scale selection

This case study concerned the formation of highway corridor alternatives within the context of the policy and plan tiers of a highway planning process proposed in this research. The so-called Millennium road has both national and international interests. Institutional interests at play in a corridor alignment were considered in this case-study – the key players being governments, UN organisations and large multi-lateral development financing banks. It was seen how although this particular highway will be only within Mongolian territory, the pints at which it exits/enters the country should necessarily be based on international interests. Thus, the extent of observation window of the reality to be studies is international i.e. national and surrounding nations. Policies in Mongolia are usually up to the aimag (province) level, with an occasional policy targeting a particular soum (county) due to recent discoveries of large mineral deposits. Due to sparse population, characteristic to this country, the county-level is de-facto the smallest useful level of analysis, as almost no policies are being implemented below this level (any of the MDGs for example). Thus the resolution considered in this study was the county level.

However, since the corridor alignments to be proposed are only limited to sections within Mongolia, the model specification limited the SMCA and the least cost analysis to the Mongolian intra-national context. To account for topographical features, a 2km resolution was used as model resolution.

The data, corresponding to the model specifications, was also be limited to national boundaries, but in a manner that could still draw meaningful information of the international interests, e.g. existing infrastructure in neighbouring countries from the border posts. Although data of higher quality was available, it was downscaled (coarsened) to meet the need of the model, which at this tier is quite coarse.

5.5 Conclusions

Howe (2007) states that *"Road investment per se is a fairly blunt instrument for affecting socio-economic change. It is not always, as is commonly supposed, the catalyst for economic growth, but creates opportunities that may or may not be exploited. Where these opportunities are taken, it is usually by the already advantaged rather than the poor, especially with major highways."* However, if the need for a highway to be implemented has been justified and approved for execution anyway, as part of a greater plan, it would be in the nation's best interest to design it in the manner that brings it maximum utility at the lowest possible cost, with transparency which when it percolates down to lower levels would bring about the most sustainable alignment. Political influences will inevitably play a role in the planning and decision making process in real life as mentioned in Figure 1.6, but if a transparent planning process generated the alternatives on which the decision would be taken, the chances that the decision is objective and politically sustainable are much higher. Furthermore, the route alternatives which will be designed within this corridor are also likely to be more holistic, as well as environmentally and socio-economically sustainable.

6 Planning of routes within corridors

The formulation and evaluation of transport route planning alternatives for the Via Baltica in Poland.

Highlights

This chapter is about the formulation of route alternatives within a chosen corridor in the constraints of an existing network, using geospatial techniques.

In conventional planning practices the assessment of environmental impacts occurs too late in the process, well after the entire route alignment is finalised.

Stakeholder engagement is confined only to ranking of a few alternatives proposed by the proponent. There is no stakeholder involvement in the actual formulation of the route alternatives. Stakeholders are thus discontented with the planning process and agitate when the project implementation begins, stalling it.

Moving the impact assessment process much upstream, to the very starting of the route alignment planning process, can enable a balanced treatment of positive and negative impacts driven by stakeholder involvement.

By addressing stakeholder concerns and priorities in the planning process, transparency and stakeholder satisfaction with the planning process can be improved much more than in current practice.

Geospatial techniques and technologies can enable better stakeholder participation and more transparent decision making in addition to aiding more sustainable planning.

This chapter based on an article published as:

KESHKAMAT, S. S., LOOIJEN, J. M. & ZUIDGEEST, M. H. P. 2009. The formulation and evaluation of transport route planning alternatives: a spatial decision support system for the Via Baltica, Poland. Journal of Transport Geography, 17, 54-64.

6.1 Introduction

Regional economic development can be attributed to a large extent to the provision of infrastructure in general and transport infrastructure in particular. As such, transport infrastructure can be instrumental to strengthening competitive positions of countries and regions. This fact has led to an increasing pressure to construct, widen and further extend highway systems. However, at lower administrative levels (i.e. finer scales), where stakeholders are not so much institutions, but people on the ground who are likely to lose their land or suffer from environmental damage, the ecological and social problems, associated with infrastructure and transport, have also generated a more critical attitude towards large transport infrastructure projects by nongovernmental organizations as well as the general public. These problems are gaining a more significant role in political decision making and voters' interest.

In the previous chapter a mega-highway planning from policy to corridor alternatives was demonstrated. Once the corridor is decided, begins the process of identifying route alternatives within the corridor. The planning must also usually take into account existing networks. Whereas the planning of corridors offers infinite possibilities from which a particular one can be chosen, the planning of routes within corridors is restricted by the bounds of the specified corridor and its pre-existing roads. Therefore choices are much more limited. At this tier, planning also needs to be more detailed, issues, concerns and stakeholders are more numerous and diverse. The reader is referred back to Figure 1.9 where this was demonstrated graphically. It is also at this stage the problems most likely to cause public agitation and project stoppage are likely to occur.

Probably one of the most prominent examples of such problems in recent years is the Via Baltica highway project in Poland. The Via Baltica expressway is a highway corridor under the TEN-T programme (TransEuropean Network of Transportation) consisting of networks of several modes of transport and trans-shipment or transfer hubs to enable continent-wide connectivity of freight and passengers to all EU member countries. The Via Baltica corridor is a corridor designed to run from Potsdam in Germany, eastwards through Poznan and Warsaw in Poland where it connects with other EU corridors before turning north towards Vilinus in Lithuania, Latvia, Estonia, Finland, northern

Sweden and northern Norway (Figure 6.1). Between Poland and Lithuania the corridor (and its scale) is restricted by the presence of non-EU territory on either side of the corridor – Kaliningrad in the west and Russia in the east.

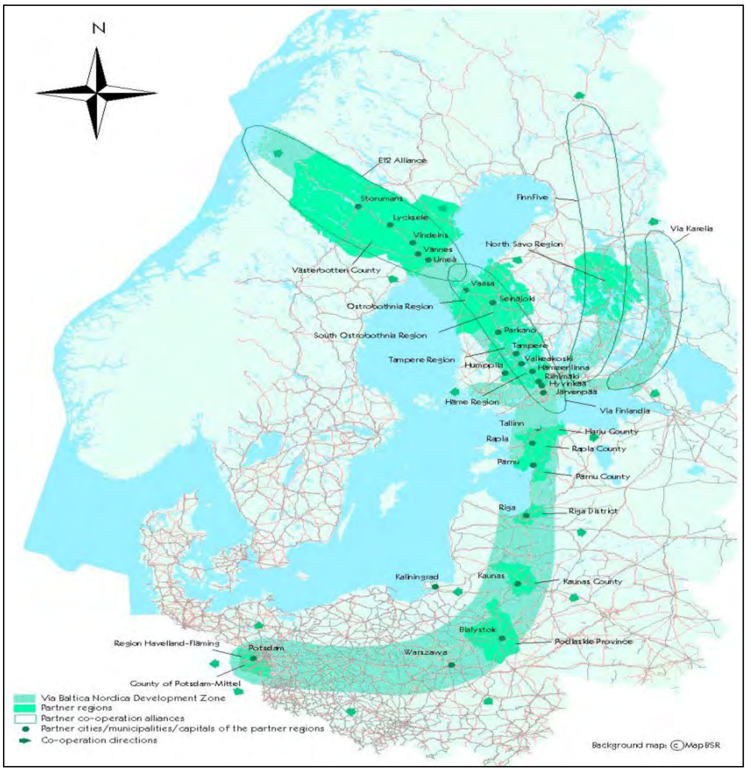


Figure 6.1: Schematic trans-European overview of the Via Baltica (Source: Interreg EU, 2007)

The highway project, commonly seen as being very important to the improvement of accessibility between EU's Central European states and the Baltic countries, got suspended in 2007 because of fear of irreversible ecological damage to important local natural sites protected under European Union (EU) law. Stakeholders and conservational organisations argued that even though several economically and environmentally more sound alternative routes existed within the specified corridor, they had never been considered as acceptable alternatives by the decision makers according to the Committee on Petitions of the European Parliament (2007) and several frontline environmental non-governmental organizations (NGOs) such as BirdLife International (2007), CEE Bankwatch Network (2005) and (OTOP (Polish Society for the Protection of Birds)) (2007). A detailed chronology, with supporting documents, of the events that led to the halt of this project by the EU is described in Keshkamat (2007).

In transport route planning generally one or a few alternative routes are proposed, often representing the interest of the proponent(s). If required, an Environmental Impact Assessment (EIA) is carried out on these alternatives. Although, EIA and SEA are meant to be effective in taking informed decisions about the proposed intervention, these alternatives are themselves devised in a subjective and/or non-spatial arbitrary manner (Steinemann, 2001). Such an approach may easily overlook route alternatives, which could be much more suitable from environmental, social and economic points of view. Thus subjective bias tends to dominate the planning at the critical early stage. Political and industrial lobbying is also known to play a key role in the identification of the route alternatives. This consequently leads to stakeholder dissatisfaction and disillusionment with the entire planning process (Fitzsimons, 2004, Valve, 1999). An efficient planning system that, through EIA or SEA, directly takes into account these environmental, social and economic considerations in formulating, assessing and selecting alternative routes facilitates sustainable infrastructure development planning.

The Via Baltica project is no exemption to this norm. Long before the EU commenced legal infringement procedures against the Polish government for breach of EU environmental laws, key officials from the European Bank for Reconstruction and Development, had already expressed the need for a transparent method that can formulate and assess effect-based transport route alternatives (Kennedy and Haumer, 1999b, Kennedy and Haumer, 1999a).

To address the above need, in this chapter the design and implementation of a systemic, spatial method for generating effect-based transport route alternatives is discussed. This method accounts for environmental regulations and concerns, while integrating equally important considerations such as transport system efficiency, safety, socio-economic demands, technical and financial viability, while also supporting stakeholder involvement. A GIS interface generates graphical as well as quantitative results, thus providing planners with a comprehensive and holistic Spatial Decision Support System (SDSS) which can enable an objective comparison of various route alternatives.

Like the previous case study, this highway also has both national and international interests, however the international interests are already addressed in a manner that has automatically decided the scale of the study – it has been stated that:

a) The highway must necessarily pass through, or within close proximity of, Warsaw, the national capital of Poland.
b) The highway must necessarily pass through EU territory only.

Further it is stated, that the highway must necessarily use only existing roads, which seen in combination with specification (b) leaves only the border post of Budzisko eligible as a destination. National interests, as expected, will lie between these two extent "limits" on the reality scale. In this case, the model extents are also the same at this scale, as the solution needed is case specific. Further, most of the data needed in the case study will be extracted from the European level data which is quite comprehensive; hence there is no dearth of data. The European dataset was clipped to the requirements of the model and reality scales. The figure below expresses this pictorially.

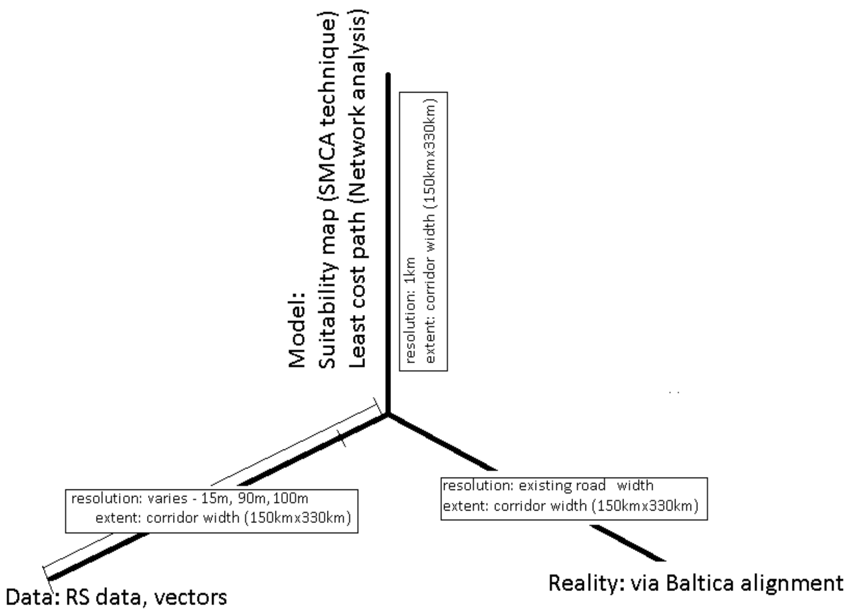


Figure 6.2: Positioning the case study.

6.1.1 Transport network planning and alternative generation

EIA and SEA are internationally accepted and often legally required procedures to minimize adverse impacts and enhance the benefits of infrastructure developments. The generation of alternatives, which is at the heart of EIA and SEA, is perhaps the most underdeveloped part of the assessment processes (Glasson et al., 1994, IAIA (International Association for Impact Assessment), 2008, Niekerk and Voogd, 1999, Sadler and Verheem, 1996, Steinemann, 2001, Treweek, 1999). Therefore, a rational, transparent stakeholder-based process for the generation of alternatives is required to be able to improve EIA and SEA and therefore decision-making.

In many of such environmental assessments a wide range of environmental effects and indicators have to be considered, requiring the management and analysis of a large amount of information and data, both spatial and non-spatial, for which GIS provides a platform for spatial modelling, analysis and assessment. Moreover, as most environmental assessments involve several alternative options and numerous stakeholders with different views and perceptions, GIS-based spatial decision support tools and particularly spatial multi criteria assessment (SMCA) tools provide effective techniques to assess cumulative impacts and to carry out a vulnerability or suitability analysis in order to evaluate alternatives. Such methods, gained universal acceptability from the work of Jankowski (1995) and Malczewski (1996) when traditional multi-criteria evaluation methods were combined with GIS and support for multiple alternatives in a group decision making environment.

Much research has been carried out in the use of GIS methods in EIA of roads (Blaser et al., 2004, Brown and Affum, 2002, Li et al., 1999). SMCA as a technique has been used also to solve routing problems in utility infrastructure, such as for pipeline routing (Rescia et al., 2006, Yusof and Baban, 2004), transmission line routing (Bailey et al., 2005) and in telecommunication network design (Paulus et al., 2008).

However, the use of GIS in the very preliminary stage of transport route planning itself has hardly been done. One of the few such examples is provided by Grossardt et al. (2001), who introduce a coherent methodology to route formulation based on environmental criteria. In this method, stakeholder priorities such as economic development, connectivity, ecological factors (wetlands and endangered species), recreational areas etc. have been combined to generate a continuous geographic surface, which functions as a composite cost or cumulative impact map. This map is a raster map in which every pixel corresponds to a weighted sum of the scores of individual impedance elements. This preliminary step of their process is similar to a SMCA approach. Grossardt et al. (2001), then proceed to use a cost-weighted distance algorithm to identify the least cost path across this SMCA surface.

The cost-distance function used by them is a (raster-based) analysis in which the impedance map (based on composite-costs) is used to determine the least cost path between a designated origin and any other point(s). The end result is a route, one cell wide, which delineates the least cost path between the points. This method tries to find the path of least impedance regardless of the length and the existing road segments. Hence, the total route length is never within the control of the method. Such a route would be uneconomical to construct and maintain, but also inefficient in terms of vehicle-kilometres and vehicle-hours. Since this method is a raster-based approach it is better suited for network and route generation rather than prioritizing and upgrading existing networks. Further, the selection of pixel size in this method seems to be done more for data-processing convenience than from a spatial effects perspective.

Based on the above mentioned discussions, a Spatial Decision Support System (SDSS) for generating and assessing effect-based transport route alternatives from existing transport networks has been developed here. This system will be described in subsequent paragraphs.

6.1.2 Geographical characteristics of the study area and the project

The Via Baltica corridor development plan, regarded as one of the European Union's highest-profile project in the Baltics, links Germany, Poland, Lithuania, Latvia, Estonia, Finland, Sweden and Norway. It aims to create a rapid and effective transport corridor from Scandinavia to Eastern and Central Europe and is expected to play a key role in the socio-economic development of the new European Union member countries (Poland, Latvia, Lithuania and Estonia) and remote underdeveloped regions in the older European Union countries of Finland and Sweden.

This portion from Warsaw (central Poland) to Budzisko (on the Lithuanian border), has run into major conflicts of interest because of the 300km long, 150km wide corridor swath overlapping with some of the most ecologically sensitive and protected areas of Europe. With 4 internationally protected nature areas (Natura 2000), 4 National Parks, 12 Landscape Parks, 10 National Reserve areas and numerous other unprotected and/or transitional woodlands of significant ecological importance lying within the corridor swath, the area is known for its rich natural bio-diversity.

A good planning would necessarily have to account for the habitats of several endangered species of flora and fauna located in this region to prevent critically fragmenting them. On the other hand, immense economic benefits of having an international highway plying through would strengthen the competitive economic position of the region. The region is very much dependant on agriculture, nature-tourism and the trade flowing through it.

The Via Baltica highway is planned as a series of upgrades of contiguous existing roads (in the corridor swath) to highway standards. Furthermore, the project embraces Europe's ideals of inter-modal transport through the parallel development of the Rail Baltica high speed railway. Figure 6.3 shows an overview of the study area and the existing road network.

The study area is predominantly a gentle rolling terrain. There are no steep slopes or sudden breaks in the terrain. The highest elevation is 300m and the lowest elevation is 59 m approximately 50 km away. Hence from the perspective of highway planning, slope regimes do not form a serious consideration in any part of this region. The soils range vastly from glacial soils and peat to fluvial soils. Peat fires are not uncommon in this area and peat also forms a serious geotechnical concern during the construction of the highway.

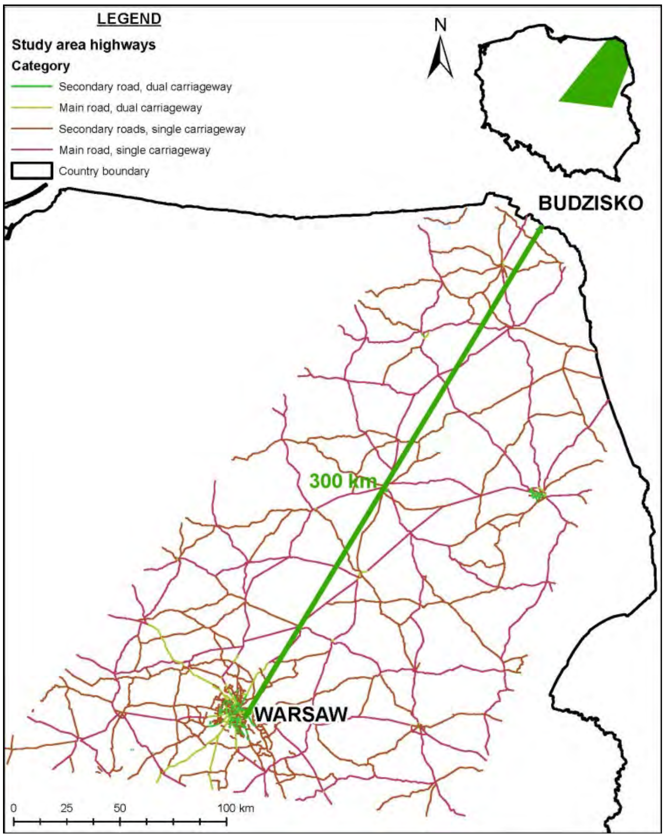


Figure 6.3: Overview of the study area[15] and existing road network

6.2 Method

In this section a Spatial Decision Support System (SDSS) for the formulation and evaluation of route planning alternatives for existing transport networks will be discussed. In order that the method gains acceptability amongst infrastructure planners, stakeholders, investors and current practitioners of EIA and SEA, the following requirements are seen as important to the method:

1. The optimal route needs to use only contiguous existing roads (in the corridor swath);
2. The method must be holistic and cross-disciplinary in its approach and should be capable of addressing the whole range of criteria and priorities relevant to the above mentioned targeted groups. It should also be

[15] Note: All maps of the study area in this chapter are in UTM-34N projection.

amenable to addition of other criteria and priorities not included in this case study;

3. The method should be developed in such a way that it can easy be used in other areas and/or other transport developments;
4. The method should be uncomplicated, transparent, back-traceable and capable of stakeholder involvement;
5. The method should be user-friendly, time and cost-effective.

In pursuance of these principles a method has been formulated as conceptualised below in Figure 6.4.

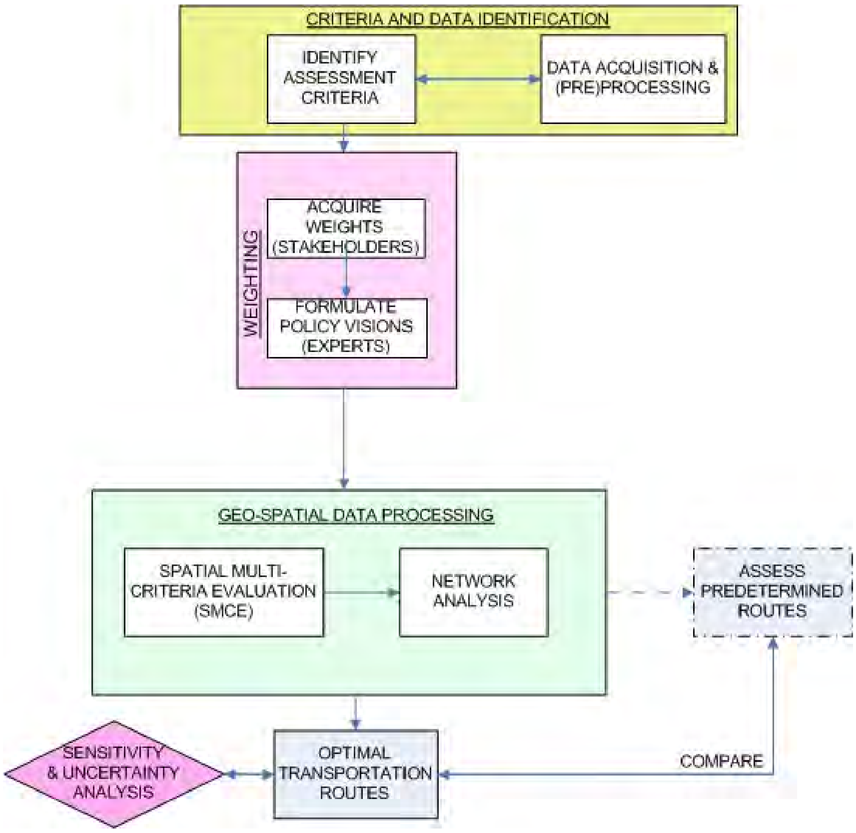


Figure 6.4: Conceptual diagram of the transportation route planning method

The method consists of 3 main components,

1. the criteria and data identification module where assessment criteria relevant to stakeholders are listed and the raw spatial data representing these criteria is assimilated into the model;

2. The weighting module, which weighs the various assessment criteria based on stakeholder preferences and policy visions;
3. The geo-spatial data processing module is the core module which takes data from the above two modules and generates optimal route maps. This is where the SMCA and network analysis are performed.

In the next sections each component is elaborated in more detail.

6.2.1 Criteria and data identification

Assessment criteria reflect the stakeholder concerns and a wide variety of impacts arising from an infrastructure development. For the Via Baltica study specifically a range of stakeholders were consulted to provide a list of criteria relevant to the planning. They ranged from representatives of environmental NGOs such as World Wildlife Fund (WWF) Poland, CEE Bankwatch Network and Polish society for protection of birds (OTOP), to Polish government bodies such as Ministry of Environment, National Park Authorities and the General Directorate of National Roads and Motorways (GDDKiA) to independent research institutes such as Institute for Sustainable Development, and several other experts and professionals such as from the University of Warsaw. These criteria are grouped according to overall sustainable development objectives into themes. The themes that have been selected in this project are

(1) transport efficiency,
(2) ecology,
(3) social impact and safety and
(4) economic costs and benefits.

Such themes are typically considered in an EIA process for transport, as listed in for example Goodenough and Page (1994), Fischer (1999, 2006) and UN-ESCAP (2002). For each criterion within a theme a corresponding criterion score has to be defined, which is associated with a (raster) map in the SMCA process within with each pixel has a suitability value.

For the Via Baltica case-study, the raster dataset is shown in Table 6.1. The raster maps are the input for the SMCA analysis further in the process. In a SMCA, criteria are usually classified into factors or constraints, based on the type of impact. A factor can be a benefit or a cost. Poor performance of a factor can be compensated by good performance of another factor, which can lead to a good overall performance in the cumulative suitability map. A spatial benefit is defined as a criterion that contributes positively to the output; the higher the value, the better it is. A spatial cost is defined as a criterion that contributes negatively to the output; the lower the value, the better it is. A spatial constraint is accordingly defined as a criterion that determines which areas in the final output map are considered as absolutely not suitable for the proposed development. As opposed to factors, poor performance of a constraint cannot be compensated by good performance of another factor or constraint. These areas will always obtain value 0 for that pixel in the final output. Criteria that represent legally protected - or otherwise unavailable - areas are usually made constraints. For example, Natura 2000 sites, which are internationally protected under EU laws for example, are considered a spatial constraint in the Via Baltica case-study.

Theme	Criteria	Explanation
Transport efficiency	Proximity to existing rail network	Spatial benefit. The closer the expressway is built to an existing rail network, the better the future intermodality
	Proximity to the proposed Rail Baltica	Spatial benefit. The closer the expressway is built to the proposed rail route, the better the future intermodality
	Current traffic density	Spatial benefit. The higher the current traffic density, the more is the reason to upgrade the road
Ecology	Internationally protected natural areas (Natura 2000 sites)	Spatial constraint. Natura 2000 sites are strictly protected under EU regulations
	Nationally protected areas, such as National and Landscape Parks (and Reserves)	Spatial cost. May be passed through but at a high cost
	Forests and semi natural areas	Spatial cost
	Wetlands and peat bogs	Spatial cost
	Water courses and lakes	Spatial cost
Social impact and safety	Proximity to urban areas	Spatial benefit. The closer the route is to an urban area, the greater the accessibility
	Risk of accidents in urban areas	Spatial cost. The closer the route is to an urban area, the greater are the incidences where resettlement of homes and establishments will be required
	Population served	Spatial benefit. The larger the population

		served, the more reasons to upgrade the road
	Hazardous areas	Spatial cost. The closer it is to a hazard prone area, the more will be the cost associated with providing safety features
Economic costs and benefits	Current farm land-use	Spatial cost. Current livelihood
	Economic zones	Spatial benefit. The more the economic activity in the area, the more reasons to upgrade the road
	Best agricultural soils	Spatial cost. Potentially productive areas
	Current status of the road (Category of the road)	Spatial benefit. The higher the current category of the road, the lower will be the engineering cost of upgrading it
	Intersections with water bodies	Spatial cost. Bridges, viaducts, culverts etc involve the construction of expensive structures. Also, the longer the bridge, the higher the cost
	Intersections with secondary roads	Spatial cost. All intersections with secondary roads need to be upgraded. This involves the construction of expensive structures such as flyovers
	Problem soils for construction	Spatial cost. Soils like peat are prone to differential settlement and pose a potentially high construction cost and/or a high maintenance cost
	Ancillary structures for urban areas	Spatial cost. The closer the route is to an urban area, the higher will be the engineering costs associated with building acoustic barriers, pedestrian subways and other ancillary structures

Table 6.1: List of themes, criteria and the explanation for use in the Via Baltica corridor study

6.2.2 Weighting of criteria and themes

With the assignment of weights the importance of a criterion or group of criteria for the purpose of the proposed activity and for decision making is emphasized. For the Via Baltica case-study, the same stakeholders representing NGOs, government bodies and academia as mentioned in previous section were asked to assign weights for the collected criteria.

In weight assignment at this planning tier a distinction is made between 'expert' weights and 'policy' weights. The assignment of weights to criteria within a theme is often based on expert knowledge. The expert determines with objective arguments the importance of criteria, often backed up by scientific knowledge (Bonte et al., 1998, Brouwer and Van Ek, 2004). The importance can be determined using e.g. the magnitude, extent, duration and significance of an effect (and the criterion derived from it). For example, in the Via Baltica case-study, within the theme ‘safety’, the criterion ‘displacement of people’ gets more weight than the criterion ‘fire hazard due to peat’.

The proponent(s), affected people and decision makers have often complete different interests. They assign different priorities to different environmental themes with more 'subjective' or political' arguments. Taking these different political weights into account is an important element of multi criteria assessment and is called assessing different perspectives or policy visions.

In the Via Baltica case-study, four policy visions (scenarios) were formulated and are summarised in Table 6.2. The equal vision represents the neutral (or reference) vision, wherein all themes have the same weight. In the social vision the highest weight is given to the theme ‘social impact and safety, in the ecology vision the highest weight is given to the theme ‘ecology’, and in the economy vision the highest weight is given to the theme ‘economic costs and benefits’. The weights were assigned according to the expected value method in which the weight vector is calculated based on a ranking of the four themes (Janssen, 1992, Saaty, 1980, Uran and Janssen, 2003). In the case-study, the use of these policy visions enables the comparison of different routing scenarios, representing the interests and perspectives of different stakeholders and policy makers.

Themes	**Visions**			
	Equal vision	**Social vision**	**Ecology vision**	**Economy vision**
Transport efficiency	0.25	0.27	0.27	0.27
Ecology	0.25	0.06	0.52	0.06
Social impact and safety	0.25	0.52	0.15	0.15
Economic costs and benefits	0.25	0.15	0.06	0.52

Table 6.2: Different visions, themes and weights used in the Via Baltica corridor study.

6.2.3 Spatial multi criteria analysis (SMCA)

In the SMCA process the geo-spatial datasets representing the different criteria and weights described above, are combined to prepare routing suitability maps for the four policy visions. Such a suitability map provides a continuous geographic surface. Each pixel value of this surface indicates the overall suitability value for routing the highway through that pixel. This type of continuous surface is similar to a friction map or an impedance map (Grossardt et al., 2001, Yusof and Baban, 2004).

The software used for this study is ILWIS 3.3 (Nijmeijer et al., 2001), which is a free open-source software having a strong SMCA module. For rasterizing all the layers representing the different geo-spatial datasets a pixel size of 1000 metres was chosen. This was done for three reasons:

1. A road layer in a vector represents a shape having no lateral dimension, whereas in real life a road does have width. Moreover environmental effects are felt more in the width direction, than along the length. Hence, the width dimension is very important to the analysis. Referring to Polish road impact studies (Cyglicki, 2005) and personal communication with Polish EIA experts, it was found that the minimum direct impact distance, also based on the European Union's Birds Directive, for existing roads is 500m from the centre-line of the road;
2. Only 2% of all the road segments used in this analysis are less than 1km in segment length, hence this will not cause a significant error in the analysis;
3. All the three raster sources used in this case study, i.e. the LandScan (Dobson et al., 2000) ambient population dataset, night-time light satellite imagery and European Soil Database (ESDB) (JRC (European Commission - Joint Research Center), 2006) data use a pixel resolution of 994m to 1 km, hence accuracy loss during re-sampling is avoided.

Based on the defined themes, spatial criteria and weights, as identified in Table 6.1 and Table 6.2, a criteria tree is built in ILWIS for each of the four policy visions. Each criterion is represented by its own map. Once all the criteria and maps are inserted in position in the criteria tree, standardization of all the criteria is done using either an (1) attribute function (for standardising according to certain class data), (2) goal function (for standardising according to a predefined minimum/maximum value) or (3) maximum function (for standardising according to the maximum value of the map), depending on the type of data represented in each criterion. As such all the input maps are standardised to utility values between 0 (not suitable) and 1 (highly suitable).

An example of a completed criteria tree for the economy vision in ILWIS is depicted in Figure 6.5.

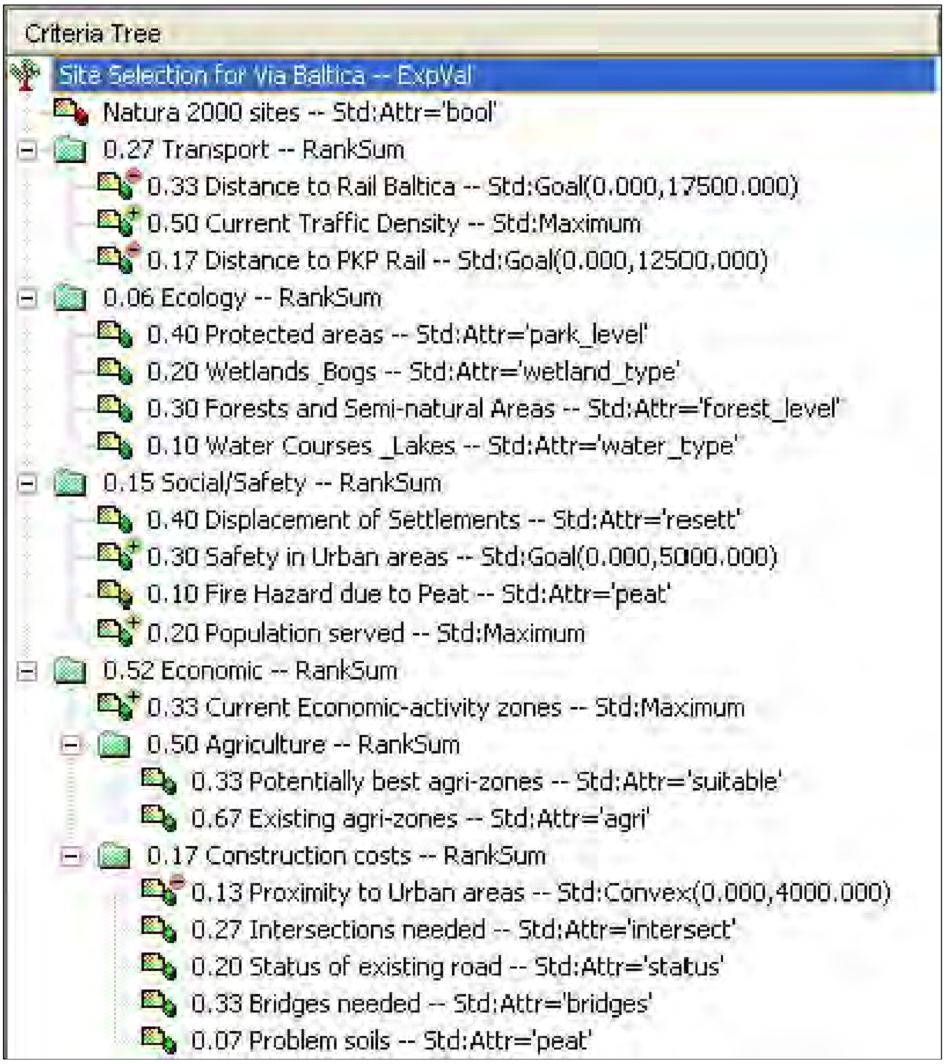


Figure 6.5: A screenshot of the completed SMCA table in ILWIS

Following this procedure four suitability maps for routing of the highway could be produced, one for each policy vision, as is depicted in Figure 6.6, Figure 6.7, Figure 6.8 and Figure 6.9.

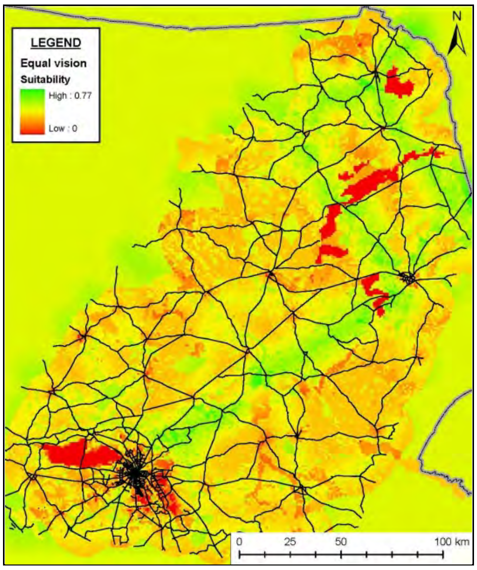


Figure 6.6: Suitability map for equal vision.

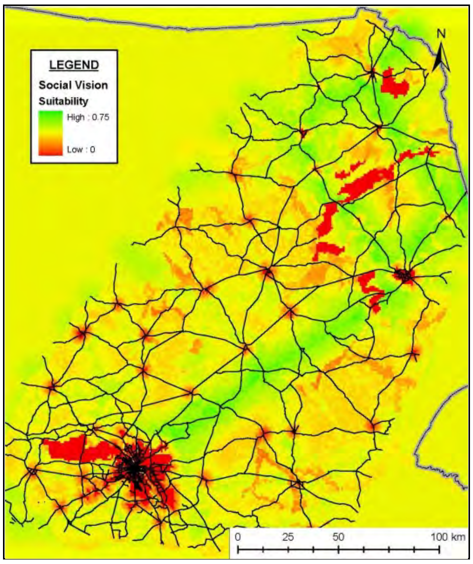


Figure 6.7: Suitability map for social vision.

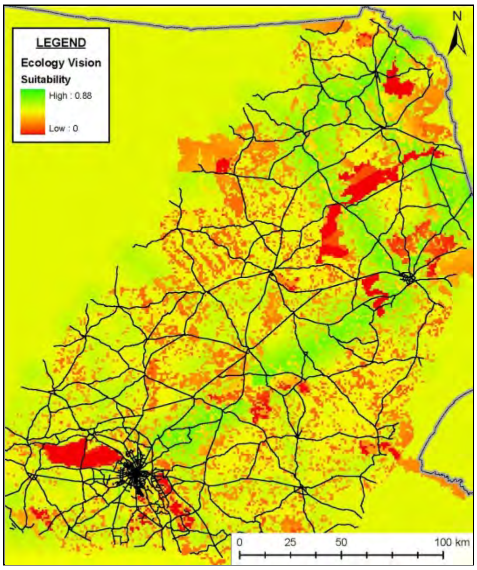


Figure 6.8: Suitability map for ecology vision.

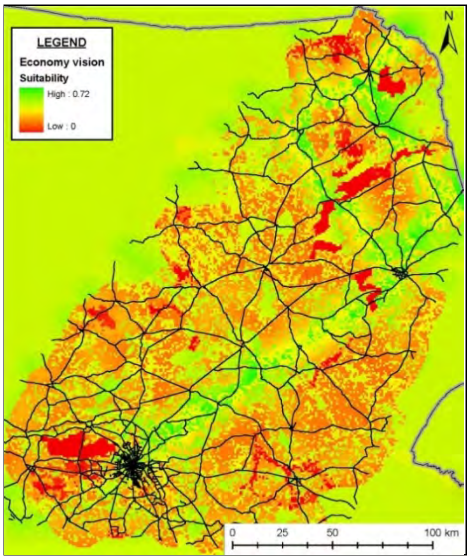


Figure 6.9: Suitability map for economy vision.

In these raster maps, areas of low suitability (valued 0) are symbolized by the colour red, while areas of highest suitability (valued 1) by the colour green. Areas of intermediate suitability are shown by intermediate colours of the gradient between red and green. The suitability values in the four final raster maps are accordingly transferred to the network and converted to impedance values to be used in a transport network analysis using ArcGIS software.

6.2.4 Transport network analysis

To commence the transport network analysis sub-component of the method, the suitability maps of the four visions and a pre-processed road vector layer have to be brought into the GIS. The line raster extraction algorithm of Beyer (2004) is used to extract the line weighted means from each resultant raster map to the road vector layer. This procedure attributes the mean suitability value of each resultant vision to each segment of the line layer based on its location. In (Beyer, 2004) the line-weighted mean (LWM) is defined as:

$$LWM = \frac{\sum_{i=1}^{n} \left(l_i \cdot v_i \right)}{L}, \qquad \textbf{Equation 6.1}$$

with, l_i is the length of a line segment i that is covering a certain raster cell, v_i is the suitability value of the raster cell from the SMCA suitability underlying that line segment, and L is the total length of the polyline of which the line segments forms part.

To find the path of least cost in the network, all the obtained values are then inverted by subtracting them from 1 (maximum suitability). Furthermore, since the pixel size in this case is 1 kilometre, this then gives the impedance per kilometre of road. In order that the total impedance of each segment (from node to node) is obtained, the impedance per kilometre value is multiplied by the corresponding length of the line in kilometres covering the raster cell. These value fields are then used as vision specific-impedances to build the network in the ArcGIS Network Analysis module. Using the LWM values, the impedance (Ω_j) of each polyline j within the road network layer is then formulated as:

$$\Omega_j = \left(1 - LWM\right) \cdot L. \qquad \textbf{Equation 6.2}$$

It should be noted that the *LWM* values are based on the underlying pixels alone. However, given the pixel size of 1km, the pre-processing steps that result in a continuous impedance surface and the line-raster algorithm itself, the possibility of having large differences between adjoining cells, for example having a pixel of high suitability underneath the line segment, and a non-suitable cell directly adjoining the underlying pixel, is tested to be highly unlikely.

Thereafter, the well-known Dijkstra's algorithm for shortest path calculations was used in ArcGIS to find the path of least total, vision specific, impedance. This procedure was repeated for all four visions, i.e. the equal-vision impedance, economy-vision impedance, ecology-vision impedance and social-vision impedance respectively. Thus four different routes having the same origin and destination have been generated. The total impedance accumulated by each route, is defined as the total route impedance (Ω_R), and can be expressed as:

$$\Omega_R = \sum_{j=1}^{m} \Omega_j ,$$

Equation 6.3

with Ω_j the impedance value of polyline *j*, and *m* the number of polylines comprising the optimal route. The higher the Ω_R value, the greater are the costs associated with the route and/or the lower are the benefits attained by it.

6.3 The optimal routes and their characteristics

Using the methodology set out before, the network is solved for path of least impedance for each of the four visions, using Warsaw as the origin and Budzisko as the destination, thus yielding four optimal routes. The properties of each optimal route show the numerical values of total route length and the total route impedance (Ω_R) for each generated route. The four route alternatives generated as such, their lengths and total route impedances, are depicted in Figure 6.10, Figure 6.11, Figure 6.12, Figure 6.13 and Table 6.3.

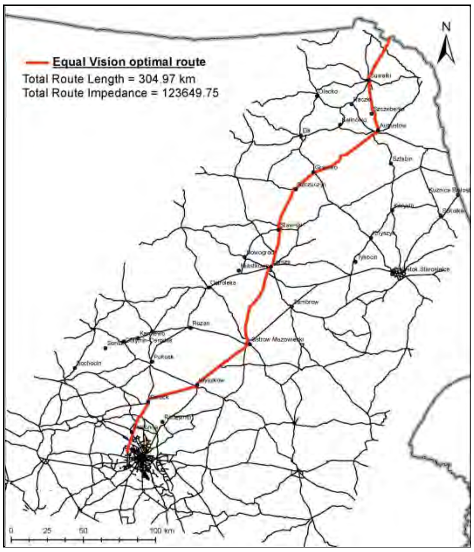


Figure 6.10: The Via Baltica expressway – the equal vision route.

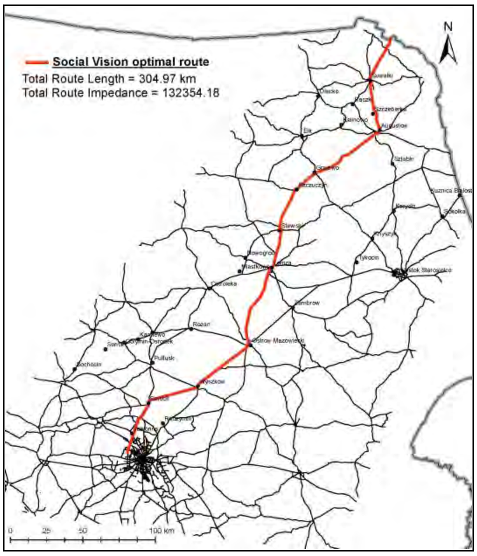


Figure 6.11: The Via Baltica expressway – the social vision route.

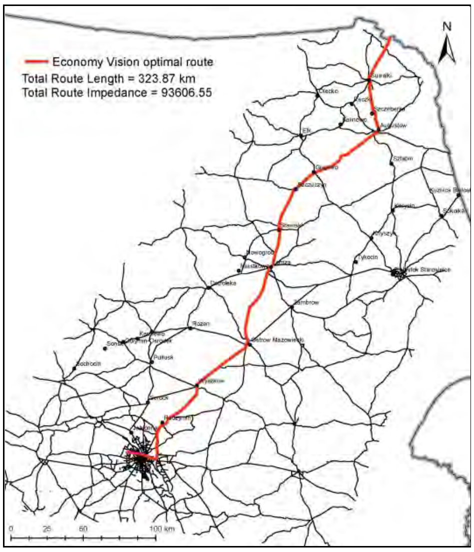


Figure 6.12: The Via Baltica expressway – the economy vision route.

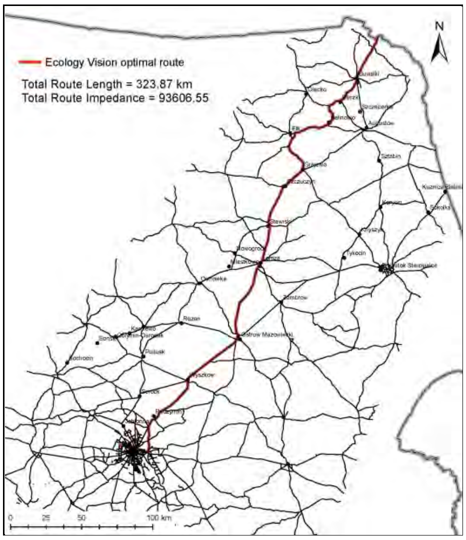


Figure 6.13: The Via Baltica expressway – the ecology vision route.

	Total route impedance Ω_R	Total route length (km)	Total route impedance Ω_R	Total route length (km)	Total route impedance Ω_R	Total route length (km)	Total route impedance Ω_R	Total route length (km)
Optimal route	123650	305	132354	305	93606	324	155823	313
Govt. preferred route	140437	344	149698	344	110033	343	174378	344
Decrease over govt preferred route (%)	13.6	12.6	13.1	12.6	17.5	6.0	11.9	9.7

Table 6.3: Comparison of the total route impedances and total route lengths of the various vision-optimal routes and the Polish Government's preferred route

From these figures and the table the geographical and quantitative characteristics for each optimal route can be seen. The equal-vision route and the social-vision optimal route have the same geographical routing but have different impedance values. They also have the shortest length of the four optimal routs generated herein. The ecology-vision optimal route has the highest impedance, while the economy-vision optimal route has the highest length of all the four routes. All four routes overlap with each other for almost 70% of total trajectory, diverging only from the city of Grajewo forward.

6.4 Assessing and comparing with a predetermined route

As has been discussed before, the practice of predetermining of route alternatives, and subsequent assessment of impacts, is prone to stakeholder dissatisfaction, see also Valve (1999). However, in addition to objectively comparing the four vision optimal routes, this methodology can also be extended to assess a predetermined route, e.g. the Via Baltica route alternative, as preferred by the Polish Government through its implementing agency called the General Directorate of National Roads and Motorways (GDDKiA).

The Polish Government preferred route alternative, as used in this case study, is shown in Figure 6.14 below. In this case, the assessment procedure uses the same built network and transport network analysis algorithm as before, but with the use of "fixed stops" and "barriers" in order to reproduce the preferred route alternative in each vision. The total route length and total route impedance (Ω_R) of the Government preferred route are compared with those of the four policy visions (Table 6.3).

From this table, it can be seen that for each vision, the Government preferred route has much higher impedance than its corresponding vision's optimal route. In addition, it can be seen that the government preferred route alternative is always longer by 20-40 km, which is about 6-13% more compared to the four optimal routes. This will significantly increase the construction and operation costs. A visual comparison, of Figure 6.15, Figure 6.16 and Figure 6.17 (optimal routes) with Figure 6.14 (government preferred route), indicates consistent:

1. avoidance of ecologically sensitive areas and protected areas;
2. accessibility to economically active areas;
3. avoidance of hazardous areas;
4. optimisation of financial costs, such as construction of ancillary structures and total length.

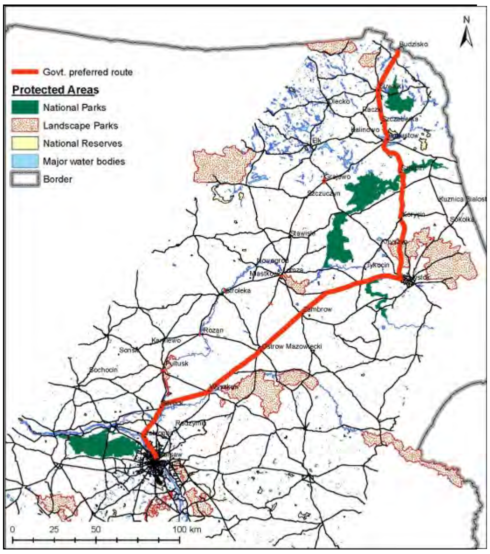


Figure 6.14: The government preferred alternative.

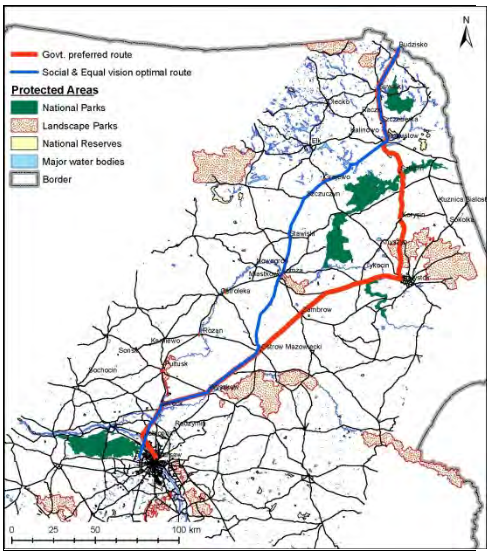


Figure 6.15: Government preferred route (red) vs. equal/social route (blue).

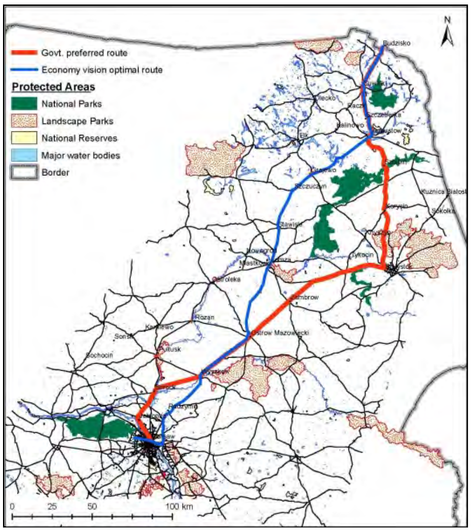


Figure 6.16: Government preferred route (red) vs. economy vision route (blue).

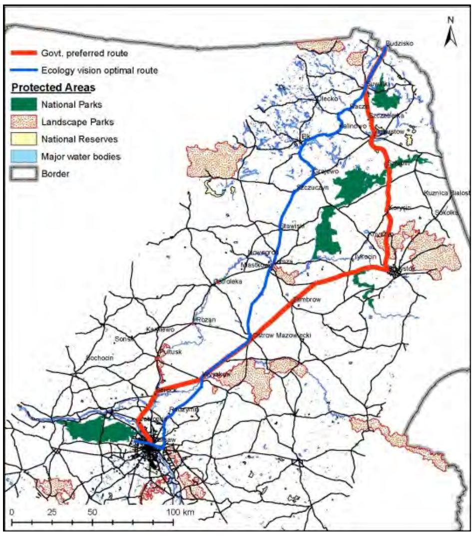


Figure 6.17: Government preferred route (red) vs. ecology vision route (blue).

6.5 Discussion

The methodology described and demonstrated in this chapter can be applied to any transport infrastructure project (such as highway or rail), which is destined for upgrade rather than for entirely new construction. Though this case study was restricted to a network covering about one-fourth of Poland, the methodology and model can be used for any scale and size, but is particularly advantageous for geographically large scale projects, thus relatively coarse network structures.

The transport network analysis procedure used in this method is a vector based approach, using an existing road network. A greater weighting is given to higher category roads in the procedure. Therefore, mainly higher categories of roads, i.e. a coarse network, are selected for use in the transport network analysis. As such, the method limits extraneous loops and detours, thus keeping the total route length under control. Furthermore, the impedance for each road segment is calculated by using the length of the segment as a multiplier, thus the total route length continues to play an important role, although not a predominant one. This way, the number of vehicle-kilometres continues to be accounted for.

For this case-study in particular, and increasingly in many other infrastructure projects, where it is mandated that, ‘no new roads should be created, only upgrading of existing roads is allowed’, the final route can only follow existing roads. Therefore only a vector-based network analysis can serve the purpose. Another advantage of this method is that the final routes that are generated continue to be polyline shapes; hence they can be used for further GIS based analysis (if needed) without requiring any additional processing.

This methodology improves upon previous scientific research in the field, by building a comprehensive methodology that integrates the use of SMCA and transport network analysis in these kinds of studies. It also improves on the research of Grossardt et al. (2001) by selecting a pixel size designed as per the effect-range of the highway and, most importantly, using the vector based network analysis.

A visual test done by overlaying the optimal routes on the original criteria layers shows that the spatial logic of each vision is firmly (and unambiguously) asserted throughout the entire route for that vision, despite it not always being obvious at first glance. This firmly proves the authors’ assumption that the existing (and popular) methodology of predetermining various route alternatives and conducting impact assessments on them can often overlook other route alternatives that may be more suitable from environmental, social and economic impact points of view.

6.6 Conclusions and recommendations

Large transport infrastructure projects such as the recent Via Baltica highway project in Poland intend to stimulate regional economic development, but are also known to have negative impacts on the local environment. The assessment of bio-physical, social and economic impacts of available routing alternatives is required to improve decision-making in the planning stages of infrastructure projects. If not done adequately, only one or a few sub-optimal alternatives are being short-listed in the end. This was also the case for the Government preferred route of the Via Baltica, which was criticized by local stakeholders and finally suspended by the EU.

The concept presented in this chapter emphasises that if stakeholder concerns and expert knowledge are coupled to the highway planning at the route-alternative determination stage itself, unnecessary biophysical, social and economic damage can be well avoided and the benefits enhanced. At the same time, a substantial increase in the utility of the project and also, increase of stakeholder confidence in the planning process can be induced.

Based on this concept, a systemic and geo-information based methodology that can formulate and assess effect-based transport route alternatives is presented. This methodology integrates environmental regulations and concerns without ignoring the equally important considerations of transport system efficiency, safety, socio-economic demands, financial and engineering viability, as well as policy considerations.

These results show that spatial multi-criteria assessment and network analysis can be coupled together to create a system of route generation based on cumulative impacts. These assessment criteria are derived from bio-physical, social and economic parameters but also involve weighting, which is obtained from stakeholder concerns, policies and expert knowledge. It is also shown that designing the pixel size as per the highway effect range works better even though the resolution is much coarser than in previous methods. The use of geospatial data including remote sensing imagery helps to fill in the spatial information gaps in the spatial decision support system presented here.

In the Via Baltica case-study four optimal routes were generated for different policy visions. As compared to the Polish government's preferred route, it was shown that all four optimal routings have less impedance and are also shorter than the government preferred route. Besides, these alternatives would also satisfy the EU's environmental laws and provide a high degree of stakeholder satisfaction. The method can be enhanced by the use of other relevant criteria such as migratory corridors, slope regimes, environmentally susceptible soils, engineering properties of soils, traffic noise, air pollution etc. which could increase the versatility of the method.

The results of the case-study demonstrate that a GIS based spatial decision support system can support authorities and planners worldwide to better respond to stakeholder demands for transport route-alternatives more systematically, transparently and objectively. The ultimate decision on which route alternative is chosen rests in the hands of political authorities. However, the methodology presented in this chapter provides decision makers with a tool that enables them to be more rational and transparent if they so wish. Hence the presented method can be used to improve the practice of Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) for transport planning, a mandatory requirement in many countries, and thus it enables sustainable transport planning.

7 Project prioritisation and mitigation

Understanding and countering transportation-caused rangeland degradation in Mongolia

Highlights

The scarcity of formal road infrastructure causes vehicle drivers to create their own tracks. As these tracks are used by succeeding vehicles, they widen into dirt-roads and thence into dirt-road corridors. The implications of this practice on environmental and socio-economic sustainability are enormous and far-reaching. It is needed to understand the practice, to identify, counter-act and mitigate them to the greatest extent possible.

A geostatistical analysis is conducted to identify factors which are significantly encouraging the widening of the corridors, shows that the factors are space and scale sensitive. A spatial multi-criteria assessment, using environmental variables identified as significant by the geostatistical analysis, is carried out to identify (map) zones highly vulnerable to the widening.

In a planned highway programme, this map can be used to prioritise development and mitigation projects, the lowest tier in a highway planning structure.

This chapter based on an article in print/in review/in preparation as:

KESHKAMAT, S. S., TSENDBAZAR, N., ZUIDGEEST, M. H. P., VAN DER VEEN, A. & DE LEEUW, J. 2011. The Environmental Impact of not Having Paved Roads in Arid Regions: An Example from Mongolia. *AMBIO.* (Accepted. In print).

KESHKAMAT, S. S., TSENDBAZAR, N. E., ZUIDGEEST, M. H. P., VAN DER VEEN, A. & VAN MAARSEVEEN, M. F. A. M. 2011. Understanding transportation-caused rangeland damage in Mongolia. *Journal of Environmental Management* (In review).

KESHKAMAT, S. S., et al. 2011. Mitigating transportation-caused rangeland damage in Mongolia. *Journal of Ecological Engineering*. (In preparation).

7.1 Introduction

The previous chapters dealt with the planning of highways to minimise impact on the environment (social and biophysical). However, what is often not realised is that the lack of a highway can also have severe negative impacts on the environment. This possible influence should also be considered in order to ensure that a highway designed as per lofty visions does serve the purpose that it was intended for, by taking into account local level environmental factors. Also at the same time, since construction processes often take several years to be completed (especially with greenfield highways), there is a need for prioritisation of projects once the route alignment is finalised. This chapter will deal with such planning issues.

It is a generally accepted perception that roads have negative environmental impacts (Clevenger et al., 2003, Forman, 2003, Roedenbeck et al., 2007). Ironically, this paradigm stems from regions where fences and regulations restrict vehicles to paved roads. The situation is different in sparsely populated rural areas in the developing world, where the scarcity of paved roads forces drivers to create their own tracks, often with considerable environmental degradation as a result. Arid and semi-arid regions, especially those with communal land ownership and easily motorable terrain, are particularly prone to this practice and the consequent degradation is widespread - plaguing regions in Central Asia, the Middle East (Batanouny, 1985), South America (Pérez, 1991) and Africa (Rickard et al., 1994). In such circumstances the paradigm contradicts its own purpose –paved roads here would in fact have a positive environmental impact, as they reduce the need for 'off-road driving'.

The land degradation that could have been avoided by the construction of paved roads can be seen clearly in satellite imagery in several countries of the world, Kazakhstan, Tajikistan, Uzbekistan, Kuwait, Bolivia and Namibia for example (Keshkamat et al., 2011). This chapter will illustrate the destructive potential that this practice is having in Mongolia.

In Mongolia the degradation typically begins when a few cycles of usage renders a track unsuitable for driving due to the formation of washboard, ruts, potholes and corrugations in the soil - a process facilitated by snowmelt, rainfall and sub-soil permafrost-thawing. Subsequent vehicles using the route deviate marginally from the existing route, thus creating a new set of track, almost parallel to the existing one. Consequently, over a period of time, a system of quasi-parallel trails is generated, denuding large swathes of land (Figure 7.1a). The communal land tenure tradition in Mongolia (a predominantly nomadic pastoralist country) and usage of rugged 4-wheel drive vehicles further compounds the problem, as there is practically no restriction to either vehicular movement or vehicle speeds.

Figure 7.1: (a) A corridor of quasi-parallel dirt-tracks crisscrossing an undulating steppe landscape, (b) a recovering dirt-track corridor 3 years after road construction (Google, 2011j), (c) at a major town (Google, 2011g) and, (d) near a muddy area (Google, 2011i).

In addition to generating dust, which affects driving safety, the compulsory use of dirt-tracks considerably increases the costs of goods and public transport due to increased fuel consumption and vehicle maintenance requirements. However, for the low traffic densities found on many routes here, these costs are small in comparison to the environmental costs. The passing of vehicle-tires decimates native flora and fauna, and also degrades habitat (Brown and Schoknecht, 2001). Moreover, vehicles compact the ground, damaging its ability to absorb and retain moisture and nutrients (Belnap, 2002). In doing so, surface water flows are concentrated and speeded up, thus leading to soil erosion, increased sediment loads in water courses and consequently, damage to aquatic habitats and water quality as well (Misak et al., 2002). Full re-vegetation of damaged swaths takes between 10-15 years after the track has ceased to be in use. However, the pioneering plants are mostly invasive weed species, such as Tumbleweed (*Salsola collina*), Fringed sagebrush (*Artemisia frigida*) and Chinese wild-ryegrass (*Leymus chinensis*), and not the native grasses such as Needle-leaf sedge (*Carex duriuscula*) and Feather-grass (*Stipa krylovii*), that are socio-economically important to the indigenous pastoralists, whose sole income is through livestock rearing (Li et al., 2006). Finally, vegetation loss, erosion and degradation of such large swaths of land spur the ever-present threat of desertification (Damdinsuren et al., 2008).

Ecologically each track within such a corridor functions as an individual road. Such multiple roads within a small location, create a larger overlapping influence-zone than a single large road (Sanderson et al., 2002). The construction of paved roads would be an effective way of restricting the environmental degradation caused by dirt-tracks (*e.g.* Figure 7.1b). However, the planning of a cross-country paved road, such as the Trans-Mongolian Highway[16], has often been criticized. Some criticism pertained to the route-alignment itself, but most of it claimed that the highway would fragment the pristine steppe and open up the land to poaching, farming and other disruptive anthropogenic activities (Trivedi, 2003). This line of deprecation takes its lessons from examples such as Brazil's Trans-Amazonian Highway (Laurance et al., 2001), or road network expansion in Bolivia (van Gils and Ugon, 2006), where increased accessibility led to degradation of an otherwise impenetrable natural forest. However, the criticism overlooks the reality of business-as-usual in Mongolia i.e. the presence of pre-existing human economic activity in the region, the easy accessibility of the steppe terrain, and the potential that paved roads could have in actually reducing land degradation by regulating vehicular movement.

An examination of the main national arterial routes including the proposed route of the Trans-Mongolian Highway, using Google Earth satellite imagery, shows that these dirt-track corridors are normally 30 to 125m wide, but get much wider near settlements (Figure 7.1c), or in muddy areas where vehicles are forced to divert from existing tracks to avoid ruts and potholes (Figure 7.1d). The maximum corridor width is about 6200m - the equivalent of a highway with 1550 contiguous lanes of 3.5m width each.

[16] Locally also known as the Millennium Road and internationally also as Asian Highway 32.

The Mongolian road network has about 45000 km of dirt roads and about 2000 km of gravel roads in its approximately 49500 km network (Onon, 2010). On the main national routes, about 11000 km of the total road network, about $3260km^2$ area is being lost to degradation caused by dirt-track corridors, corresponding to an average width of 164m. The remaining, less intensively used 34,000 km, will predictably contribute at least as much. This estimate corresponds well with the estimated degradation of over 7000 km^2 by Batjargal et al. (2006). Along only the proposed two-lane Trans-Mongolian Highway, an average corridor width of 788m (equivalent to 225 lanes) is affected. This translates to $2367km^2$ of land, whereas the construction of the paved 20m wide Trans-Mongolian Highway will take about $60km^2$.

The National Statistical Office of Mongolia (2008) finds that private car ownership in Mongolia is doubling almost every 5 years - all at the expense of ecosystems incapable of coping with this mounting pressure. Thus the degradation is likely to further worsen unless roads between main populated centres are paved.

7.1.1 Implications for policy

Arid and semi-arid regions in countries such as Mongolia contain some of the world’s most fragile and vulnerable ecosystems. The depredation wrought by dirt-track corridors could endanger rare species further and reduce genetic diversity, which is a matter of serious concern. Widespread land degradation also leads to a decline of the ecosystem services’ structure and to environmental problems, such as loss of productive pasture land, increased water- and wind-erosion and dust storms.

The construction of paved roads is known to cause a variety of direct and indirect negative environmental impacts by opening up the land, thereby easing vehicular mobility, natural resource exploitation and economic activity (N.R.C. Committee on Ecological Impacts of Road Density, 2005). However, in regions without major obstacles to off-road driving, the lack of paved roads results in considerable environmental damage and economic loss also. A balance, therefore, needs to be struck.

Recent EIA reports for road construction projects in Mongolia mention the degradation from dirt-track propagation that can be avoided by the proposed project. However, the direct and indirect environmental and socio-economic costs of the land degradation due to the lack of paved roads have not been systematically audited yet at a larger scale. Application of such project-based EIAs to approve or reject the development of a road might well conclude that the proposed road introduces landscape fragmentation, if dirt-track corridors are not taken into account. Hence, wherever dirt-track propagations are observed, there is a need for a SEA of transportation plans and policies – one which will account for the costs of not having a paved road, while also considering the priorities for biodiversity conservation at the national and supra-national level.

Satellite imagery confirms that dirt-track propagation is not only a pressing issue for Mongolia, but in other countries with arid and semi-arid regions as well (for example: (Google, 2011a, Google, 2011b, Google, 2011e, Google, 2011h)). Like in Mongolia, as *per capita* incomes in developing countries rise, vehicle ownership and road transport increase steeply. If road infrastructure development in such regions does not keep pace with growing economic activity, the negative effects of dirt-track propagation will increase. Regulatory instruments such as EIA and SEA are used to control and mitigate the impacts of new road construction, but no such instrument exists to control dirt-track propagation. A widespread awareness of this phenomenon and its implications is necessary. At the same time, a deeper understanding of it and its causes is needed in order to design measures to counter it.

We postulate that the widening of the dirt roads in rangelands is clearly due to the drivers' response to environmental aspects. There are some environmental factors that support this type of driving and others that constrain it. Most of these factors act in combination, rather than singularly. General Ordinary Least Squares regression (OLS) and Geographically Weighted Regression (GWR) techniques were used to investigate and compare whether the observed corridor widths are correlated with environmental variables, and if so, what are the characteristics of their influence. In transport studies, such locally varying relationships have also been studied by (Du and Mulley, 2006, Mulley and Tanner, 2009, Propastin et al., 2008, Yao-Dong and Jia-yi, 2010), and Geographically Weighted Regression (GWR) (Fotheringham et al., 2002) in particular, has shown promising results. If such rationality can be established plausibly, a spatial vulnerability model can be developed as a platform to enable planners and engineers to use the outcomes of this study.

7.2 Study area

As mentioned in Section 5.1.1, Mongolia is a country with an extremely low population density of 1.7 person/km² (2008) which is mostly dispersed throughout the countryside. This has contributed to the lack of nationwide formal road infrastructure in the countryside and led to the proliferation of private 4-wheel drive cars. Since democratization in 1990, the Mongolian economy has seen a steady economic growth and, like other developing countries, is seeing the corresponding rise in vehicle numbers and vehicle usage. However, investment in construction of asphalt roads has not seen a corresponding increase (Figure 7.2) due to other national priorities, but also because of the vast distances involved. Dearth of formal infrastructure support for the increased vehicular traffic widens the dirt-tracks into dirt-roads and thence into dirt-road corridors.

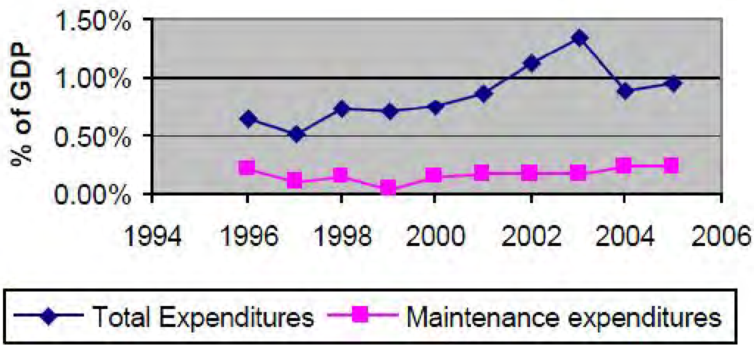


Figure 7.2: Mongolian road expenditure vs. GDP. (Source: Kenny et al. (2007))

Since 2005, the Mongolian government through Asian Development Bank and World Bank has begun building of a formal system of paved roads across the country as a means of social and economic connectivity for its people. The paving of essential arterial roads is undoubtedly the best solution, but road networks of this magnitude and expanse, do not get built nor funded overnight, and so without prejudice to future efforts in this direction, low-investment, low-risk mitigation measures to reduce or control corridor widths are the call of the hour.

7.3 Methods

In order to counter the propagation of the dirt-track corridors, it is first necessary to analyse how these corridor-widths are influenced by the environment. Our analysis consisted of 3 main stages: data preparation and statistical analysis and vulnerability modelling. The flowchart of the process is shown in Figure 7.3.

7.3.1 Data preparation

Data preparation consisted of:

1. Identification of the dirt tracks and dirt track corridors;
2. Identification and mapping of factors that influence the corridor widths;
3. Spatialising these criteria (directly or through proxies that can be used to represent them).

Identification of dirt-tracks and dirt-track corridors

The denudation caused by dirt tracks occurs on a very large extent, usually beyond visual range when the observer is on level ground, and is noticed only from high-ground or when the terrain slopes acutely. This makes its field measurement very difficult. Satellite imagery offers the best possible way to identify the extent and spread of the dirt corridors at a country-wide scale. Identification of dirt corridors however, poses a challenge – at high magnification (low extent) it is impossible to identify the logic of the behavior of each 'strand' of track, thereby making the decision to 'bundle' it into a certain corridor, or not, difficult; whereas at large extent (low magnification) it is not possible to identify the finer 'strands' clearly and thus some may be missed.

Automated image interpretation using feature extraction software on remote sensing imagery of different spectral and spatial resolutions was initially used to try to identify individual tracks from which the linear directional means could then be appraised. However, in addition to false positives such as lineaments and dry gulches, the spectral, seasonal, orthographic, topographical and geometrical variability associated with such a large scale geographical study at the requisite high resolution prevented accurate and usable feature extraction (see Figure 7.4).

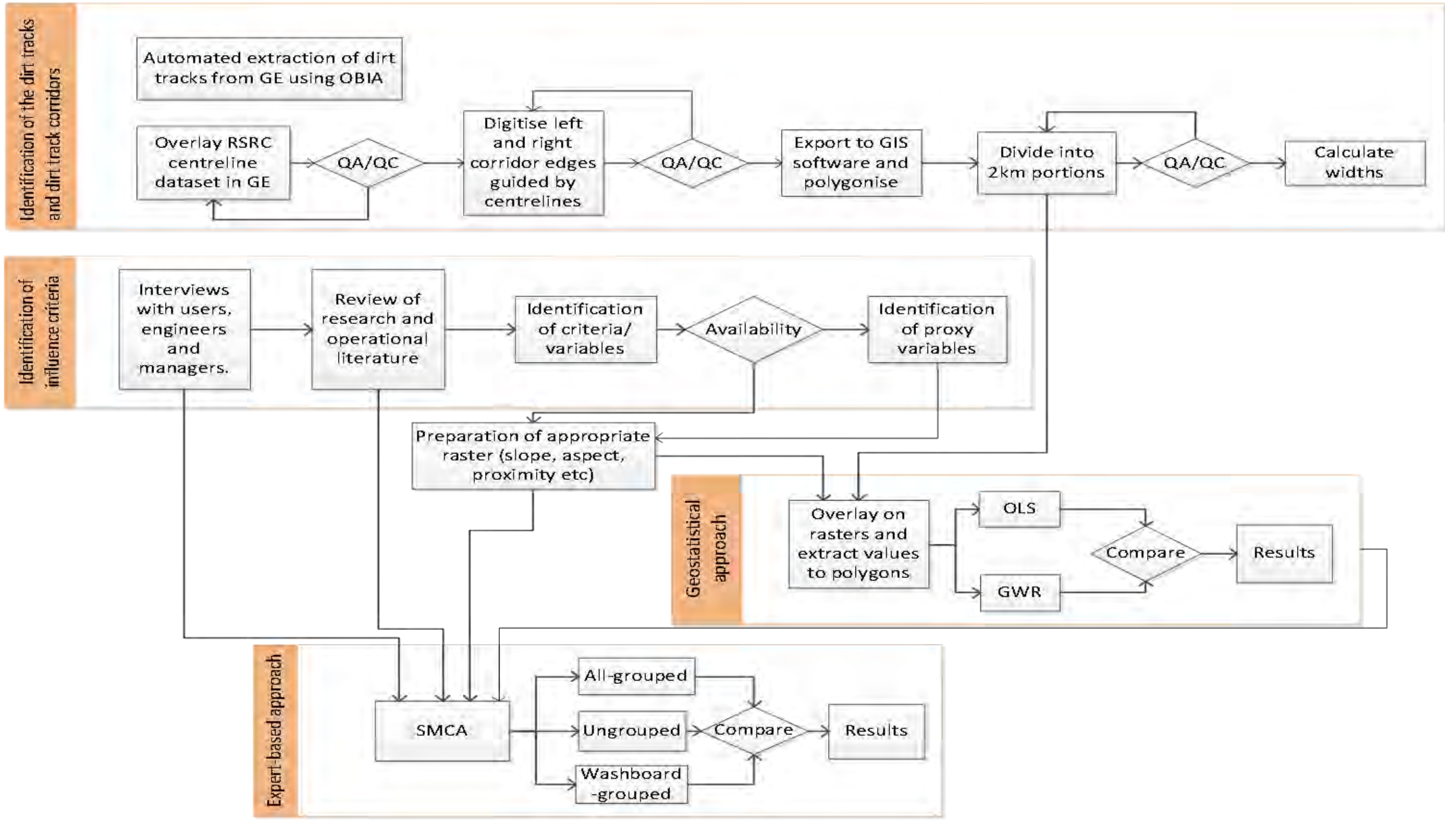


Figure 7.3: Flowchart of the method

Hence, we resorted to digitizing corridors from Google Earth through visual interpretation and cognitive analysis. Trained image interpreters at the Institute of Geography (Mongolian Academy of Sciences, Ulaanbaatar) visually interpreted satellite imagery, grouping quasi-parallel tracks into corridors and digitized these corridors manually on screen in Google Earth. Manual feature extraction combined with local knowledge, although more laborious than algorithm-driven machine analysis, generally leads to better results (Hu et al., 2004), particularly for informal features such as dirt roads (de Leeuw et al., 2011, Zhou et al., 2006). The Google Earth image database for Mongolia currently consists of a mosaic of Geo-Eye imagery (sub-meter resolution), SPOT imagery (2.5m resolution) and Landsat imagery (15m resolution), acquired from 2005 to 2011. Although paved roads and dirt tracks were better visible in the higher resolution imagery, they could be well-discerned even in the lower resolution Landsat imagery due to characteristic linearity and contrast with surroundings.

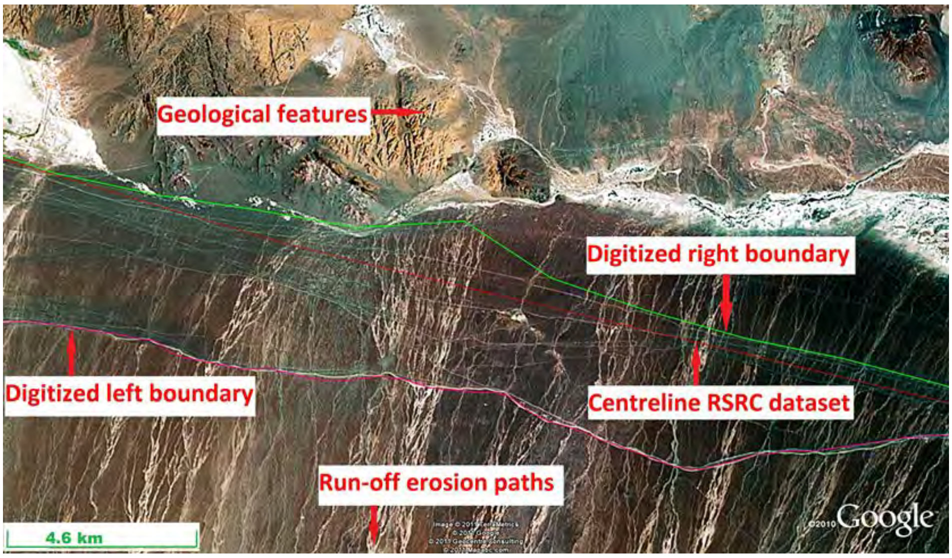


Figure 7.4: Example of the digitizing process of a route corridor (Authors' elaboration on Google Earth image (Google, 2011d)

Left and right margins of all the arterial road corridors were digitized in Google Earth using the digital dataset of roads of Mongolia obtained from the RSRC. The use of Google Earth gave us the ability to zoom (magnify) in and out of the imagery seamlessly, thus allowing us to capture fine detail without losing sight of the larger perspective. Both edges of a corridor were traced fully in Google Earth, one edge at a time for each route and converted into a vector shape file. Figure 7.4 shows an example of the digitizing process of one such route corridor. The left and right border lines of each corridor were then used to create polygons in GIS software. We studied 37 main national corridors, having a total length of 11,000km throughout the country (see Figure 7.5).

Figure 7.5: Arterial routes of Mongolia[17] studied in this analysis overlaid on the land-use map for context.

After deriving the route polygons, station lines were generated at every 2km distance and each route polygon was then split at every 2km along the length, thus creating a dataset with track width attributes of each 2km long section of each route. Average width of each portion was accordingly calculated and used for further analysis. A preliminary examination of the digitized polygons showed that less than 12% of the 11,000km we studied was under 25m width, and about 65% was more than 75m wide (Figure 7.6).

[17] Note: All maps of Mongolia in this chapter are in UTM-48N projection.

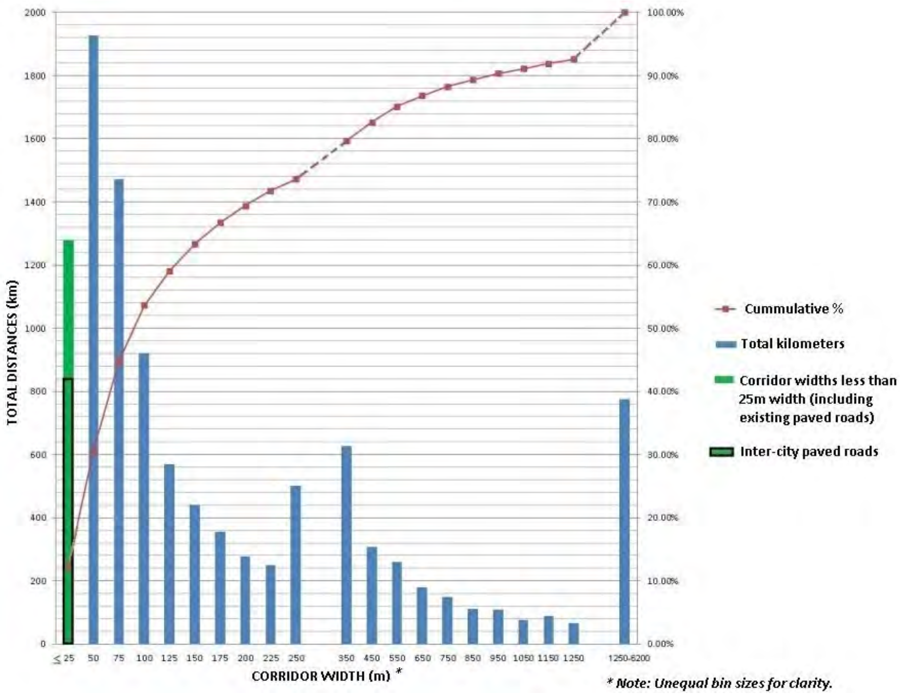


Figure 7.6: Average corridor widths in meters.

Identification of environmental factors

In consultation with long-distance professional drivers, national government road engineers and private sector highway engineering consultants in Mongolia, we identified several environmental factors as having potential causal relationship with the observed corridor widths. These are:

1) Proximity to key attractors, such as main towns and population centres,
2) Proximity to water features, such as rivers and river crossings, lakes and marshes,
3) Terrain conditions, particularly slope and snow-depth.
4) Vegetation density and greenness, and
5) Road condition, particularly washboarding ,

Through Taberlet et al. (2007), Bitbol et al. (2009) and Shoop et al. (2006), we find that the main parameters influencing the washboarding of dirt road surfaces are the surface soil grain size, soil moisture, soil surface temperature and traffic density. Taberlet (2007) and Mays and Faybishenko (2000) also found that light and medium vehicles (such as passenger cars and SUVs), because of their ‘softer’ suspension systems and higher speeds, are mainly responsible for washboarding, while heavy vehicles are mainly responsible for the deeper damages such as rutting. In addition to causing washboarding, the soil temperature, moisture, grain-size also influence dust formation which affects driving behavior as drivers try to evade it.

We also found from the National Atlas of Mongolia (Dorjgotov, 2009), as well as from Mongolian road engineers (Keshkamat, 2008d, Keshkamat, 2008e, Keshkamat, 2008f), that most of the snow in this country comes from the North-West which is the main snow carrying wind direction, causing deep snow drifts on the northern aspect of the mountains and less snow depth on the southern aspects. Field observations revealed that due to an inherent local respect for productive pasture land, areas with denser (and greener) vegetation seem to be less prone to widening than drier and less vegetated areas which are easier perceived as ‘wasteland’, although it is these very dry areas that are the most vulnerable to desertification. Forests and shrub-lands are uncomfortable to drive through and hence also avoided.

Based on these enquiries and assessments 15 environmental factors were identified as being the most relevant for analysis. The different environmental factors are spatialized in a GIS environment for further spatial analysis. In order to maintain a common pixel size for further processing, all the rasters were either generated, or resampled, to a common resolution of 600m.

Table 7.1 shows the factors, data sources and spatialisation process. Euclidean distance rasters were generated from vector maps of the province centres, county centres and water-bodies. Slope and aspect maps were derived from the hole-filled Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM) of Jarvis et al. (2008). We spatialised the RSRC’s Annual Average Daily Traffic (AADT) enumeration charts for 2008 by allocating vehicle counts from the tables to the road vector map.

8-day MODerate resolution Imaging Spectroradiometer (MODIS) imagery[18] for 1st - 8th July 2009 was obtained and mosaicked for the whole of Mongolia.

[18] Data obtained from the Land Processes Distributed Active Archive Center (LP DAAC), (lpdaac.usgs.gov).

Using raster calculation, it was used to generate maps of topsoil Grain Size Index (GSI) as per Xiao et al. (1992), Land Surface Temperature (LST) as per Wan (2010), Soil Moisture Index (SMI) as per Sandholt et al. (2006) and Modified Soil Adjusted Vegetation Index (MSAVI) as per Qi et al. (2011). Imagery for this particular period was chosen because the end of spring and onset of summer is the most optimal (balanced) period to derive parameters such as MSAVI, Soil Moisture and GSI in Mongolia.

Factor	Variable	Source	Preparation
Road condition	Total Traffic density	RSRC	Table->vector -> raster
	Ratio of light to heavy traffic		
Proximity 1	Distance to province centre	NGIC	Vector data -> Euclidean Distance map
	Distance to county centre		
Proximity 2	Distance to main rivers		
	Distance to secondary rivers		
	Distance to main river crossings		
	Distance to secondary river crossings		
Proximity 3	Distance to lakes and marshes		
Snow-depth	South aspect	SRTM-DEM	Classified processed DEM raster
Terrain type	Terrain slope		
Road condition	Soil grain size (GSI)	MODIS – 8 day image	Raster calculation and resampling
	Land surface temperature (LST)		
Vegetation	Vegetation index (MSAVI)		
	Soil moisture (SMI)		

Table 7.1: Preparation of (environmental) variable layers.

The raster layers prepared in the previous stage were overlaid by the (split) corridor polygon layer and the polygon-raster intersection tool in the Geospatial Modelling Environment (Beyer, 2009) was used to calculate the mean value of the raster cells of each variable for each section polygon.

7.3.2 Analyses

To ascertain the significance and magnitude of the environmental factors' influence on the corridor width, inferential statistical analysis was conducted by comparing the observed parameter - corridor width (dependent variable) with local values of identified environmental criteria layers (independent variables) using geographically weighted regression (GWR). If a rationality could be established it was proposed to use the factors identified as statistically significant to map the vulnerability to widening throughout the country, by using SMCA based evaluation and prediction.

7.3.2.1 Statistical analysis

The peculiarity of this statistical analysis is that it deals with a phenomenon that has predominantly linear and sequential characteristics in an areal context. There is no dearth of examples of the use of spatial and non-spatial statistical analysis in studying areal phenomenon. Statistical analysis of linear sequential phenomenon is carried out through spatial lag functions, and although fewer, also exist. In this study, spatial lag functions could not be used either, because flow is bidirectional, i.e. y is a function of $y-1$, as well as $y+1$.

Hence, to the best of our knowledge an analysis of this nature, wherein there is bidirectional dependency between the properties of contiguous cells and yet at the same time, another (different) relationship - a geographically varying one at a regional level - has not been conducted before. OLS and GWR were used to understand and explain the relationship between the explanatory variables and the corridor widths.

GWR can effectively handle the spatial autocorrelation and non-stationarity inherent with spatial data, unlike for example conventional regression techniques, such as ordinary least squares (OLS) that can only produce average and global parameter estimates (Gao and Li, 2011). GWR can produce local parameter estimates that can be used to ultimately generate mathematical equations which can be used elsewhere to identify zones which may be susceptible to widening, for example (Propastin et al., 2008, Gao and Li, 2011, Li et al., 2010). To confirm if the local parameters have a strong influence on the dirt track propagation both OLS and GWR are applied in this study.

Ordinary least squares regression

Multi-collinearity of environmental variables was tested using threshold of Variation Inflation Factor (VIF) 10 since interrelated environmental variables can produce a considerably misleading result. Stepwise OLS was then employed to explain the average width of the dirt roads based on environmental variables using a non-spatial statistical package (SPSS), for the whole dataset at once and for each of the 37 routes separately as well. This regression can be indicated as shown in Equation 7.1.

$$y_i = \beta_0 + \sum_k \beta_k x_{ik} + e_i$$

Equation 7.1

where y_i is the predicted value of the response variable at location i, β_0 is the intercept, β_k is the slope coefficient for independent environmental variable k, x_{ik} is the value of the variable k at location i, and e_i indicates the prediction error for location i. In this equation, the estimates of the model parameters are assumed to be spatially stationary.

To check the suitability of the OLS model, Moran's I was then calculated for the residuals of the model prediction for identifying spatial autocorrelation using GIS software (ArcGIS). The OLS model was then calibrated to deal with the spatial dependence using a spatial autoregressive model in SAM (Rangel, 2010).

Geographically Weighted Regression

In the next stage, Geographical Weighted Regression (GWR) was conducted in SAM (Rangel, 2010) to deal with the issue of spatial autocorrelation and to investigate the spatial variability in the influence of the environmental variables. This can help the examination of the spatial pattern of the local estimates to get better understanding of possible hidden causes of the observed values (Fotheringham et al., 2002). The GWR model extends OLS global regression by creating a local regression equation for each observation point, and can be expressed by Equation 7.2 (Fotheringham et al., 2002):

$$y_i = \beta_{0(\mu i, y i)} + \sum_k \beta_{k(\mu i, y i)} x_{ik} + e_i$$

Equation 7.2

where $(\mu i, y i)$ is the spatial location of observation point i, $\beta_{0(\mu i, y i)}$ is the intercept for location i and $\beta_{k(\mu i, y i)}$ represents the local slope coefficient for independent variable k at location i.

Parameter estimates in GWR are calculated by giving a weight to all observations points around a specific point *i* based on their spatial proximity to it. The observations closer to point *i* have greater influence on the local parameter estimates for the location, and thus, are weighted more than points further away (Fotheringham et al., 2002).

Estimated parameters in GWR are highly dependent on the bandwidth size of the selected kernel. As bandwidth gets larger, parameter estimates will be closer to that of OLS global model. Conversely, as the bandwidth decreases, parameter estimate will highly depend on the observations close to regression point i, and there will be increased variation. Therefore, selecting optimum bandwidth is very important in GWR. The optimum bandwidth is calculated either by a cross-validation technique (CV) or Akaike Information Criterion (AICc) which aims to minimise the score. Bandwidth selection based on the AICc was used in this study, as the lower the AICc the better is the model prediction. Once the bandwidth calibration process is complete, GWR uses the optimal bandwidth to fit a weighted regression model at each point, the parameter estimates being output. Through multiple iterations the optimal bandwidth was identified to be 100.11 km. In other words, observation points from an extent of 100 km around its location were included in local regression for observation *i*.

The *t*-value for each parameter estimate and each regression point was calculated to test if the influence of certain environmental variable is significant at 90% confidence level for specific observation points. Significant influences were then spatially mapped for each variable.

7.3.2.2 Vulnerability Modelling

After the statistical analysis was used to establish whether the corridor widths are a product of rational human response to environmental variables and if so, what the influencing variables are (individually or in combination). Its results showed that relationships can be established between the environmental factors and the corridor widths. However, although such an analysis can provide crisp, objective and credible information, it can only deliver this information for the routes that were digitised. Given that there is a (known) total of about 48,000 km of dirt-track corridors over the country, the information that decision makers actually need in order to anticipate and alleviate the problem, needs to be more spatial by nature and easily usable. We propose a vulnerability map, derived from the criteria that the geostatistical analysis confirmed as statistically significant, which shows spatially the potential for dirt-track propagation over the whole jurisdictional area.

Knowing that different criteria have different magnitudes of influence in the formation of the corridor widths, we used SMCA to generate the weighted combination of different spatial criteria into a cumulative widening probability map. In our interviews we found that when they are driving, the road users (drivers) are not self-conscious of how their actions are influenced by environmental stimuli. Their acts of choosing one track not another, or of avoiding washboarded or muddy tracks and creating new ones altogether are usually intuitive and experience-based rather than conscious decisions. It was thus difficult for them to decipher their own actions, either in prospect or in retrospect.

However, we also found that the influence of topographical factors versus locational factors was somewhat more reasoned, although still not always clear-cut. We also found that washboarding and its related effects were a primary concern. Hence we developed three SMCA trees, using the same factors (SMCA criteria) to simulate the 3 cognitive methods which we used to seek their weights.

1. All criteria ungrouped, compared pairwise against each other (Figure 7.7a).
2. Washboarding related criteria grouped and internally compared; all other criteria (including washboarding) compared against each other Figure 7.7b).
3. All criteria subgrouped under 4 principal attributes – locational, topographic, washboarding and vegetation (Figure 7.7c).

Grouping of criteria enables the comparison of a 'theme' of criteria against another 'theme' or an individual criterion. For example, comparing washboarding (which includes soil and other factors) against terrain slope is different from comparing soil-type directly against terrain slope.

Figure 7.7: The three SMCA models - 'No group', 'Washboard grouped' and 'All grouped'.

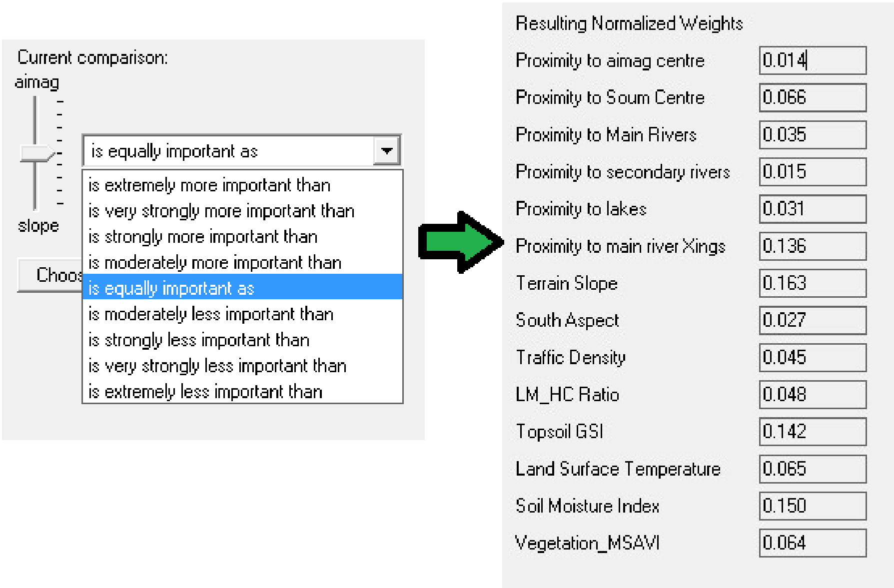


Figure 7.8: Pairwise weighting in ILWIS

The criteria were then weighted as per their expected contribution to widening by a pairwise comparison of the various parameters in ILWIS by the experts. Pairwise comparison method was chosen because it simulates reality, by mimicking the choices that the driver must make while driving. ILWIS uses the Analytical Hierarchy Process (AHP) algorithm to generate the weights from the results of the pairwise comparison. The pairwise weighting process is seen in Figure 7.8.

The raster maps, which were created to represent the 15 criteria spatially, were then linked to their respective criteria. Standardisation for each criterion was then carried based on its expected influence range/s and effect on vulnerability to widening (Table 7.2) based on local and professional expertise from the conducted interviews and personal fieldwork.

Criteria	Influence	Type of standardisation	Value
Total Traffic density	Benefit	Goal	0, max
Ratio of light to heavy traffic	Benefit	Convex Goal	0, max
Distance to province centre	Benefit	Goal	0,15 (km)
Distance to county centre	Cost	Goal	0,15 (km)
Distance to main rivers	Benefit	Goal	0,10 (km)
Distance to secondary rivers	Cost	Goal	0,5 (km)
Distance to main river crossings	Combination	U shape	0,30 (km)
Distance to secondary river crossings	Cost	Goal	0,5 (km)
Distance to lakes and marshes	Cost	Goal	0,15 (km)
South aspect	Cost	Convex Goal	0, max (DD)
Terrain slope	Cost	Goal	0, 10 (%)
Soil grain size (GSI)	Cost	Convex Goal	-1, 1
Land surface temperature (LST)	Benefit	Convex Goal	300, 325 (^{o}Kelvin)
Vegetation index (MSAVI)	Cost	Convex Goal	-1, 1
Soil moisture (SMI)	Combination	U shape	0, 1

Table 7.2: Table showing standardisation parameters of the criteria.

The SMCA ontologies used in this table (and in ILWIS) are:

1. Cost: the lower the value of the criteria, the more the vulnerability
2. Benefit: the higher the value of the criteria, the less the vulnerability.
3. Combination: has an influence both as a cost and as a benefit. For example, soil moisture – if too low, the soil is dry and forms dust easily, causing drivers to widen to avoid a preceding vehicle's trailing dust. However, if there is too much soil moisture, it also creates conditions for widening, as drivers try to avoid muddy areas.

Once the weighting and standardisation process was concluded resultant maps, which represent 'vulnerability to dirt-road propagation' were generated. Values of the raster cells lie between 0 and 1. The resultant image, a continuous raster surface, was then reclassified into 5 discrete classes, based on the probability of dirt-road propagation due to the combination of environmental factors, viz.

1. Very low
2. Low
3. Medium
4. High
5. Very high

As mentioned before, field observation of the widening is very difficult to quantify. Hence the same approach (assessment/observation from satellite imagery) was taken to carry out an accuracy assessment of the various models. Each of these classified maps was converted into the appropriate format (kmz) and overlaid on Google Earth. 100 random sample points were generated throughout the country and also overlaid in Google Earth. By adjusting the overlay's transparency, the three model outputs were separately compared with the underlying imagery within proximity of each of these points.

The accuracy assessment was conducted by generating a confusion matrix, for each model's output, similar to that used in remote sensing image classification accuracy assessment (Congalton and Green, 1993). The best-fit model was identified by comparing overall accuracies, omission and commission errors of all 3 models for the set of 100 randomly generated sample points distributed throughout the country.

The results of the statistical analysis, vulnerability modelling and accuracy assessment are presented in the following section.

7.4 Results

7.4.1 Statistical Analysis

7.4.1.1 Ordinary Least Square Regression

Stepwise linear regression for all segments together (the global model) resulted in a R^2 of 0.05 meaning that only 5% of the average widths of dirt road corridors can be explained by some environmental variables. Proximity to main rivers and their crossings, proximity to province centre, lake and slope, aspect, light to heavy traffic ratio, MSAVI, GSI and soil moisture variables were found to be significant in the global OLS model. Slope, vegetation, distance to lake, main river and its crossings and soil moisture acted as constraints to the widening of dirt roads, whereas the others appeared to aid it.

Stepwise regression was also applied individually for each of the 37 road routes. Coefficient of determination improved significantly - in the range of 0.13-0.7, as compared to all routes combined. From the results, it was clear that some variables were playing an important role in some routes but not for across-the-board for all. The detailed results of route-wise OLS are shown in Table 7.3.

Corridor	Sample size	Adj. R^2	Influencing environmental variables							
All	5248	0.051	LM_by_HC	Di_prov	Di_river	Di_riv_cros	Di_lake	Aspect	Slope	GSI
AltaiBurgastay	174	0.487	Di_county	Di_riv_cros	Di_str_cros	Di_lake	SMI			
AltaiRashaant	380	0.426	Total_traf	Di_county	Di_river	Di_riv_cros	Di_lake	Aspect		
AltaiTsagaanUul	271	0.180	Total_traf	Di_county	Di_stream	Di_lake	LST			
BarunUrtBichigt	136	0.580	Di_prov	Di_county	Di_riv_cros	Di_str_cros				
BarunUrtChoibalsan	101	0.144	Di_river	Ruggdness						
OlgiiDayan	116	0.219	Di_county	Slope	SMI					
OlgiiHovd	111	0.211	Di_riv_cros	MSAVI						
BayantesArtssuurii	38	0.351	Di_riv_cros							
BayantesMoron	164	0.334	Total_traf	Di_prov	Di_lake	Slope				
BulganDarhan	118	0.019	Di_county							
BulganLun	117	0.188	Aspect	SMI						
ChoibalsanEreentsav	115	0.138	Di_county	Di_lake						
ChoibalsanHavirga	62	0.601	Di_str_cros	Slope						
ChoibalsanSumber	184	0.553	Di_county	Di_riv_cros	Di_stream	Di_str_cros	Aspect			
Choibalsan	13	0.791	Di_county	Di_river						
DarhanAltanbulag	72	0.420	Di_county	Aspect						
DarhanUlaanbaatar	99	0.354	LM_by_HC	Di_county	Di_stream	Di_lake				
HovdManhan	43	0.737	Di_prov	Di_riv_cros	Di_stream	Di_str_cros	Di_lake			
LunUlaanbaatar	46	0.574	LM_by_HC	Di_river	MSAVI					
ManhanAltai	158	0.288	Di_county	Di_river	Di_stream	Di_str_cros	LST			
ManhanYarant	224	0.197	Di_stream	Di_lake	GSI	LST				
MoronBulgan	175	0.501	LM_by_HC	Di_prov	Di_county	Di_riv_cros	Di_str_cros	Slope		
MoronHuvsgul	50	0.630	Di_county	Di_stream	Di_lake		SMI			
OndorhaanBaruunUrt	114	0.225	Di_riv_cros	Di_stream	Di_str_cros					
OndorhaanChoibalsan	159	0.534	Di_prov	Di_riv_cros	Di_stream	Di_str_cros	Aspect	LST		
RashaantBayantes	407	0.147	Total_traf	Di_str_cros						
RashaantLun	120	0.327	Total_traf	Di_prov	Di_riv_cros	Di_lake	LST			
TsagannuurOlgii	33	0.620	Di_stream	Slope						
TsagannuurTurgen	102	0.428	Di_river	Di_riv_cros	Di_stream	Di_str_cros	Di_lake	Aspect		
TurgenKhandgait	43	0.156	Di_river							
TurgenUlaangom	19	0.647	Total_traf	Di_lake						
UlaanbaatarGashuunSukhait	459	0.202	Total_traf	LM_by_HC	LST					
UlaanbaatarOndorhaan	157	0.358	Total_traf	Di_prov	Di_riv_cros	Di_stream	Di_lake	LST		
UlaanbaatarZamynUud	322	0.439	Total_traf	LM_by_HC	Di_county	Di_riv_cros	Di_stream	Di_lake	MSAVI	
Ulaanbaatar	29	0.907	LM_by_HC	Di_county	Di_riv_cros	Di_stream	Di_str_cros	Aspect	Slope	
UlaanbaishiinTsagannuur	17	0.922	Di_river	Di_lake	LST					
UlaangomBayantes	171	0.201	Di_prov	Di_county	Di_river	Di_str_cros				
UlaangomHovd	128	0.366	Di_prov	Di_county	Di_stream	Di_str_cros				

Notations: (Please refer route node names from Figure 4.)
Di_prov = Distance to province centre; Di_county = Distance to county centre; Di_river = Distance to main rivers; Di_stream = Distance to secondary rivers; Di_riv_cros = Distance to main river crossings; Di_str_cros = Distance to secondary river crossings; Di_lake = Distance to lakes and marshes; Aspect = South aspect (snow depth); Slope = Terrain slope; Total_traf = Total Traffic density; LM_by_HC = Ratio of light to heavy traffic; GSI = Soil grain size; LST = Land surface temperature; SMI = Soil moisture index; MSAVI = Vegetation index.

Table 7.3: Results of route-wise OLS regression

Calculation of the local Moran's I for the residuals from global OLS model showed that the effect of spatial autocorrelation is highly significant in a few specific routes, particularly those showing high R^2 in OLS, thus rendering their 'good' results questionable. Moran's I for the residuals of all routes in the dataset was 0.7 indicating a high spatial autocorrelation. Given the z-score of 58.84, it also indicated there is less than 1% likelihood that this clustered pattern could be the result of random chance. Thus, it is not likely that the corridor width can be explained well by other environmental variables when global OLS regression is used since spatial dependence (autocorrelation) of the residuals violates the basic assumption of OLS regression. Correcting for spatial autocorrelation in the global model improves the R^2 to a modest 11% compared to the model which did not consider spatial influence. We consider this score insufficient to draw further conclusions on dirt track propagation. Given the high local variability, a GWR analysis was felt needed.

7.4.1.2 Geographically Weighted Regression Results

Using a Gaussian Spatial function and the optimized Fixed Bandwidth (b) at 100.11 km, and the 15 predictor variables, the GWR analysis yielded the following results. The adjusted R^2 for GWR is 0.45, meaning that GWR could explain 45% of the corridor widths using our environmental variables - a very good score considering that this is a study related to individualistic human behaviour. The model summary of GWR results, and comparison with OLS results, are shown in Table 7.4.

Comparison Measure	GWR	OLS
Sigma	235636	633
Effective Number of Parameters	242	16
Akaike Information Criterion (AICc)	80072	82615
Correlation Coefficient (r)	0.689	0.231
Coefficient of Determination (R^2)	0.475	0.054
Adjusted r-square (R^2 Adj)	0.449	0.051
F (R^2)	18.738	19.743
P-value (R^2)	0	<.001

Table 7.4: Model summary showing of GWR and OLS results

Local correlation results (i.e. local adjusted R^2) obtained by the GWR analysis can be mapped with regards to its locations to observe the model-fit spatially, as in Figure 7.9. A few areas in the central, southern, and western parts have a weak model fit (<0.2) while, most of the areas have moderate model fits (>0.2).

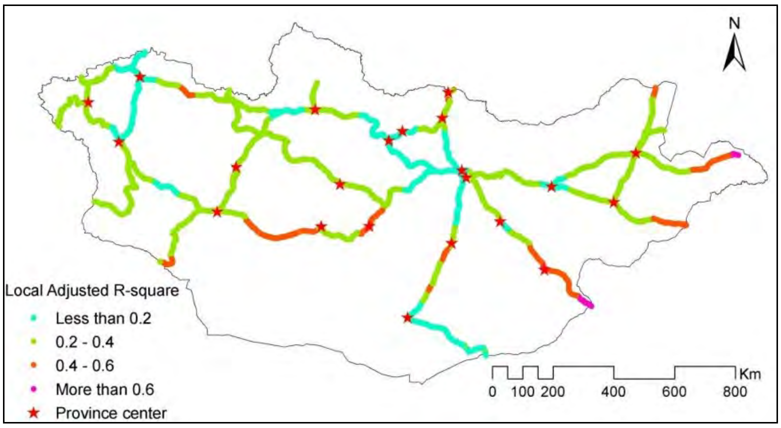


Figure 7.9: Correlation results of GWR analysis.

The model validity can be verified by examining the residuals. Figure 7.10 and Figure 7.11 compare the residuals of GWR and OLS. The green-line in Figure 7.10 shows how residuals are spatially less correlated by better model-fitting in the GWR analysis.

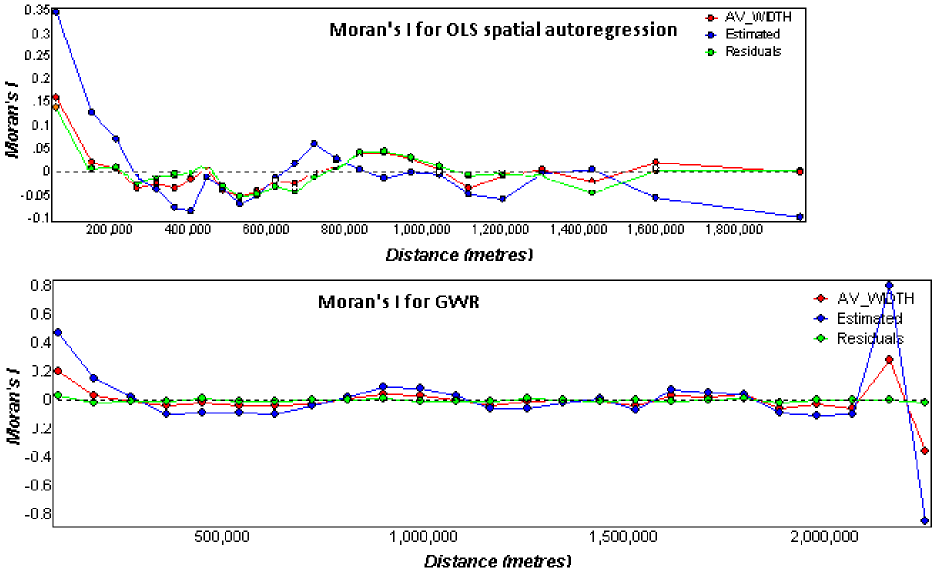


Figure 7.10: Comparing the Moran's I of OLS and GWR analyses.

In Figure 7.11, it can be seen that, as expected, the GWR model fits the data better i.e. there is less error of spatial autocorrelation in the GWR analysis. Moran's I for GWR residuals was 0.23, while for OLS residuals it was 0.39 (for the same bandwidth), implying that GWR addresses the issue of spatial autocorrelation.

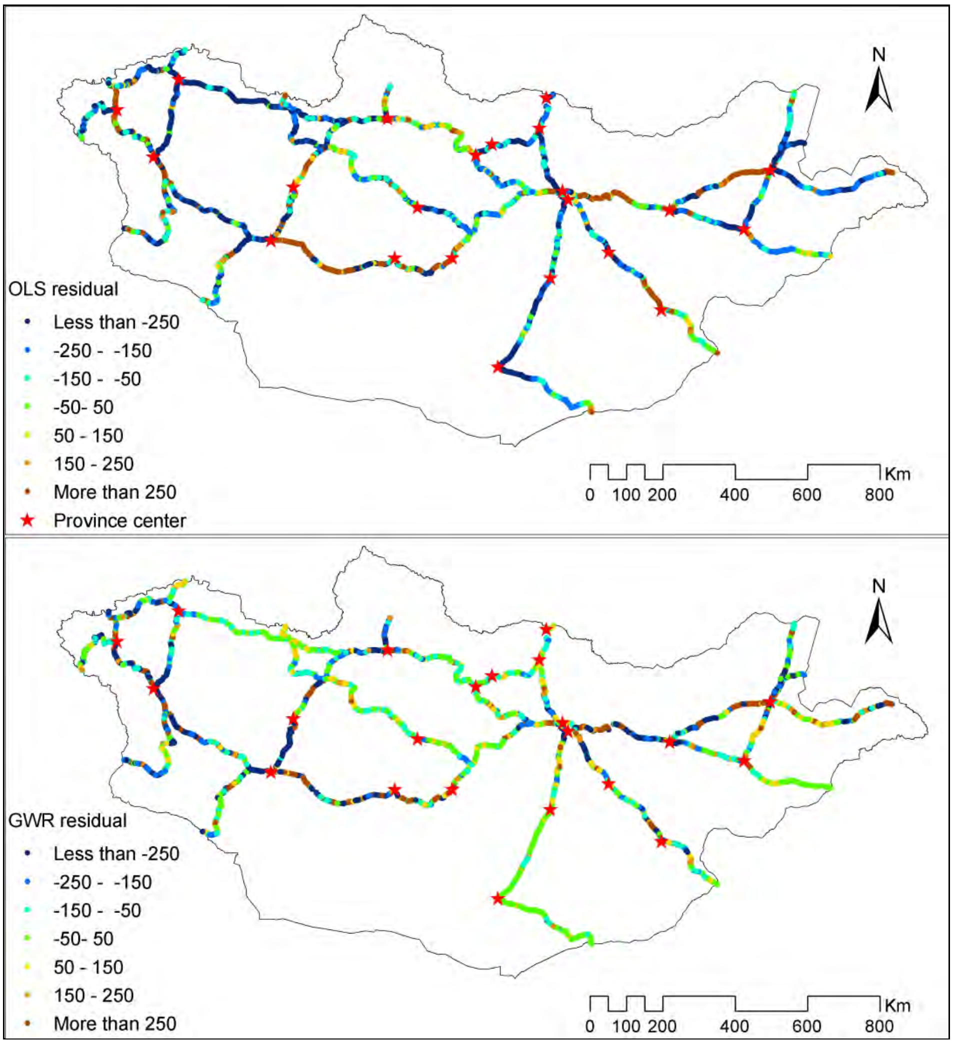


Figure 7.11: Comparing the residuals of OLS and GWR.

In order to understand the influence of each of the local environmental factors shown in Table 7.1 on the dirt track corridor width, the GWR coefficient of each parameter qualified by its t-value (at least 90% confidence level) was mapped to the polygon shape file and is described below factor-wise.

Proximity to population centres

Proximity to province centre (Figure 7.12 top) has the strongest influence in the national capital region – as distance to province centre increases corridor widths increase (the further the wider). This could be because most of the province centers usually have a 10-20km asphalt approach road. However, near the province centres of Arvayheer and Uliastay, this effect is reversed due to the mountainous terrain. On the other hand, proximity to county centres (Figure 7.12 bottom) has a negative influence (the closer the wider), as drivers branch off from the main trajectory towards their chosen destination (and vice-versa), except in the Sainshand- Zamiin Uud route where proximity to streams overpowers the general trend.

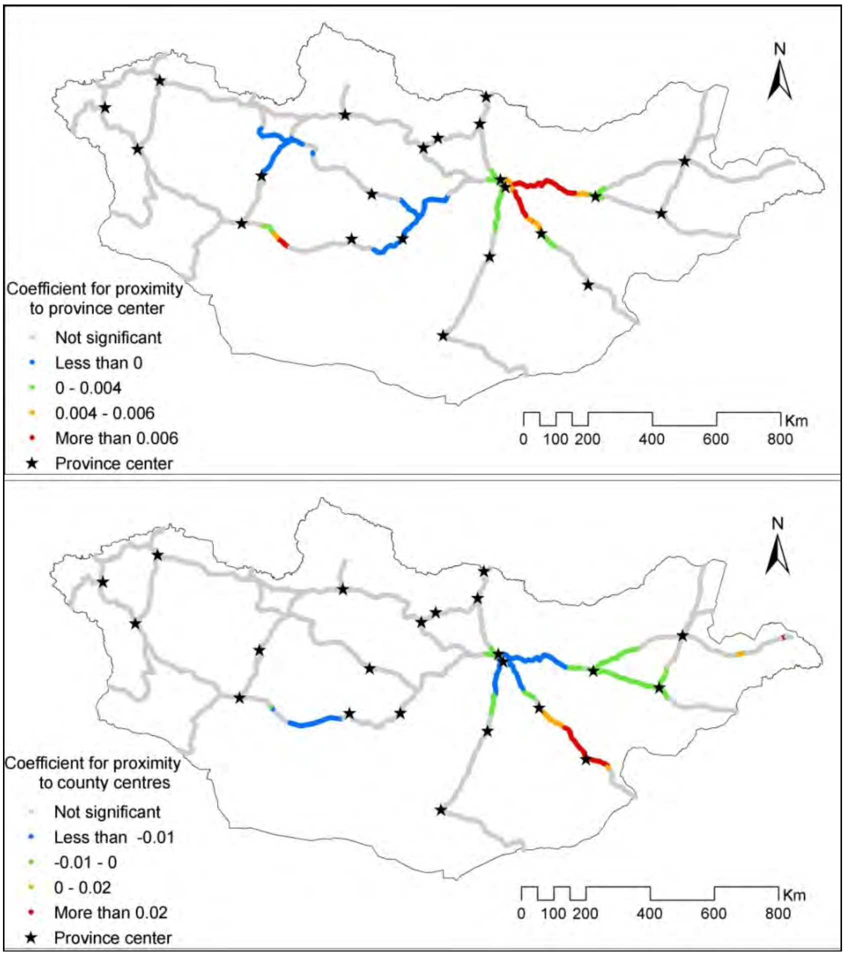


Figure 7.12: Influence of proximity to population centres on corridor widths.

Terrain conditions

Our expectation that the greater the slope, the narrower is the corridor was confirmed (Figure 7.13 top). In the areas around Ulaanbaatar and Baruun Urt the influence is greater. The influence of aspect (Figure 7.13 bottom) is understandably only in very small areas, in the Hentiy mountain range (near Ulaanbaatar, Bagannuur and Choir), the 'souther' is the road, the more is the width, whereas in other areas, the 'norther' it is, the wider is the corridor. It could be because in those areas there is less snow cover in the northern aspect due to local meteorological conditions.

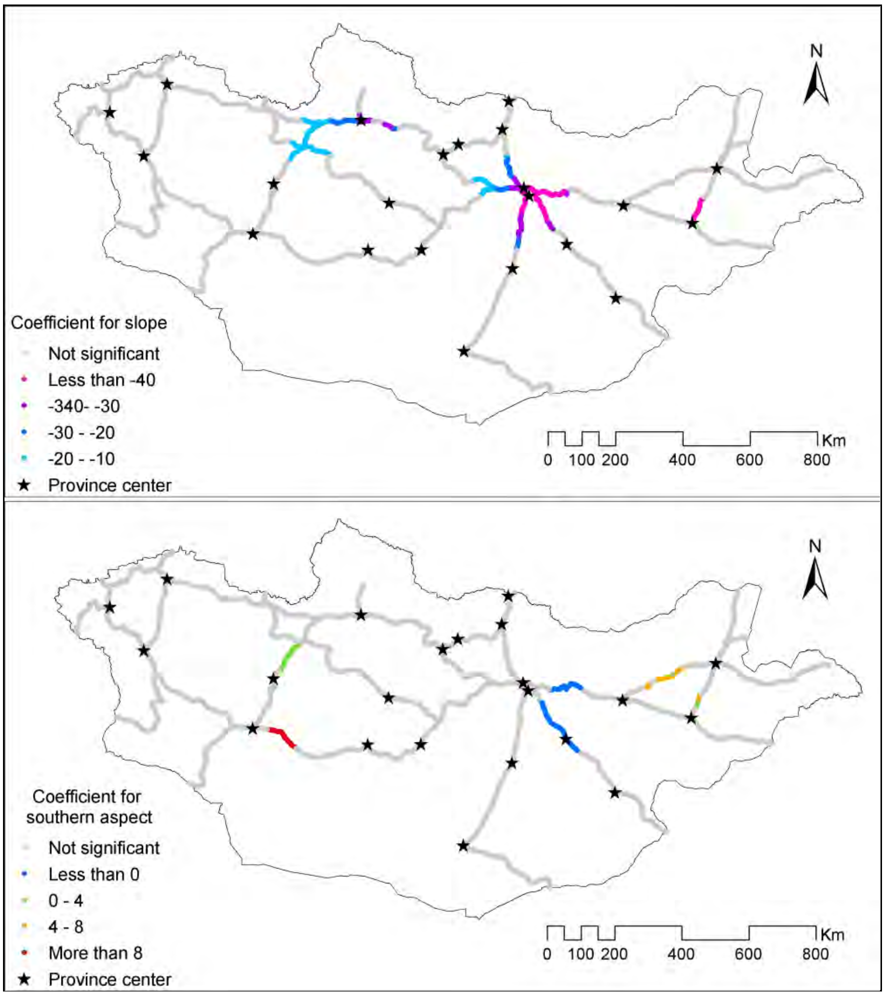
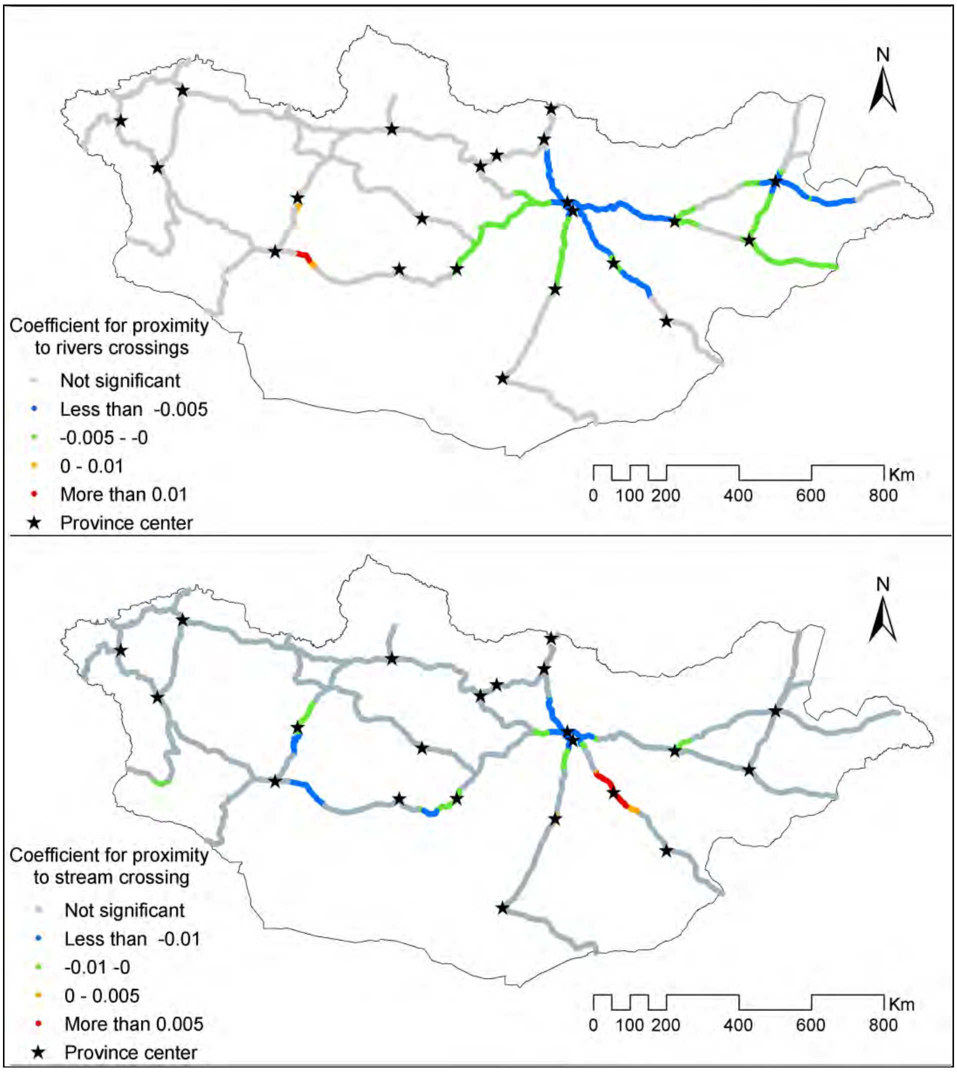


Figure 7.13: Influence of terrain factors on corridor width.

Proximity to water features

Figure 7.14 shows that in general, the proximity to main rivers and seasonal streams had a positive influence on the width (further the wider), except for smaller rivers and lakes/marshes, which had a reverse effect (closer the wider), perhaps because of the muddiness associated with such features. Conversely, the proximity to river crossings and seasonal stream crossings had a negative influence on the width (closer the wider).



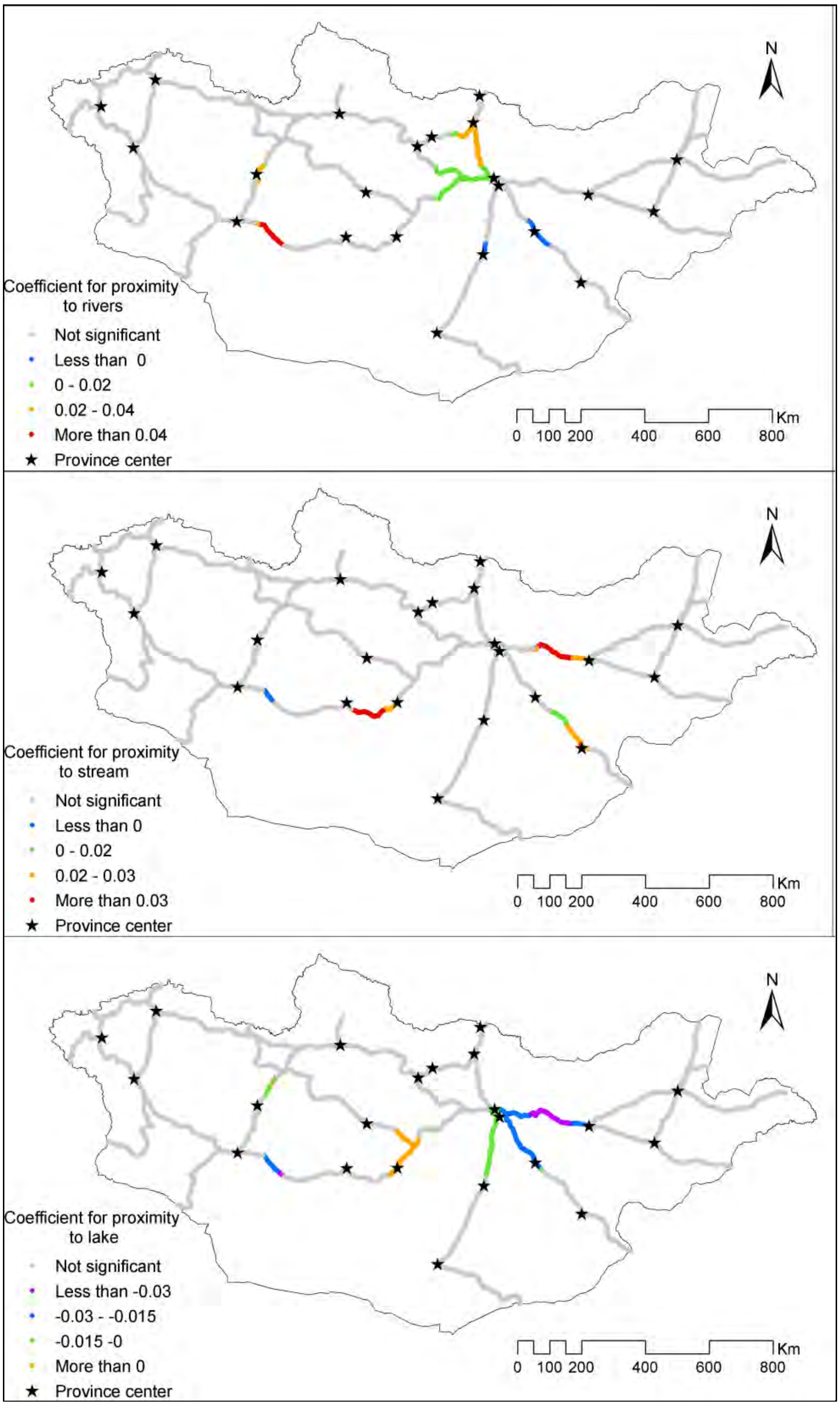
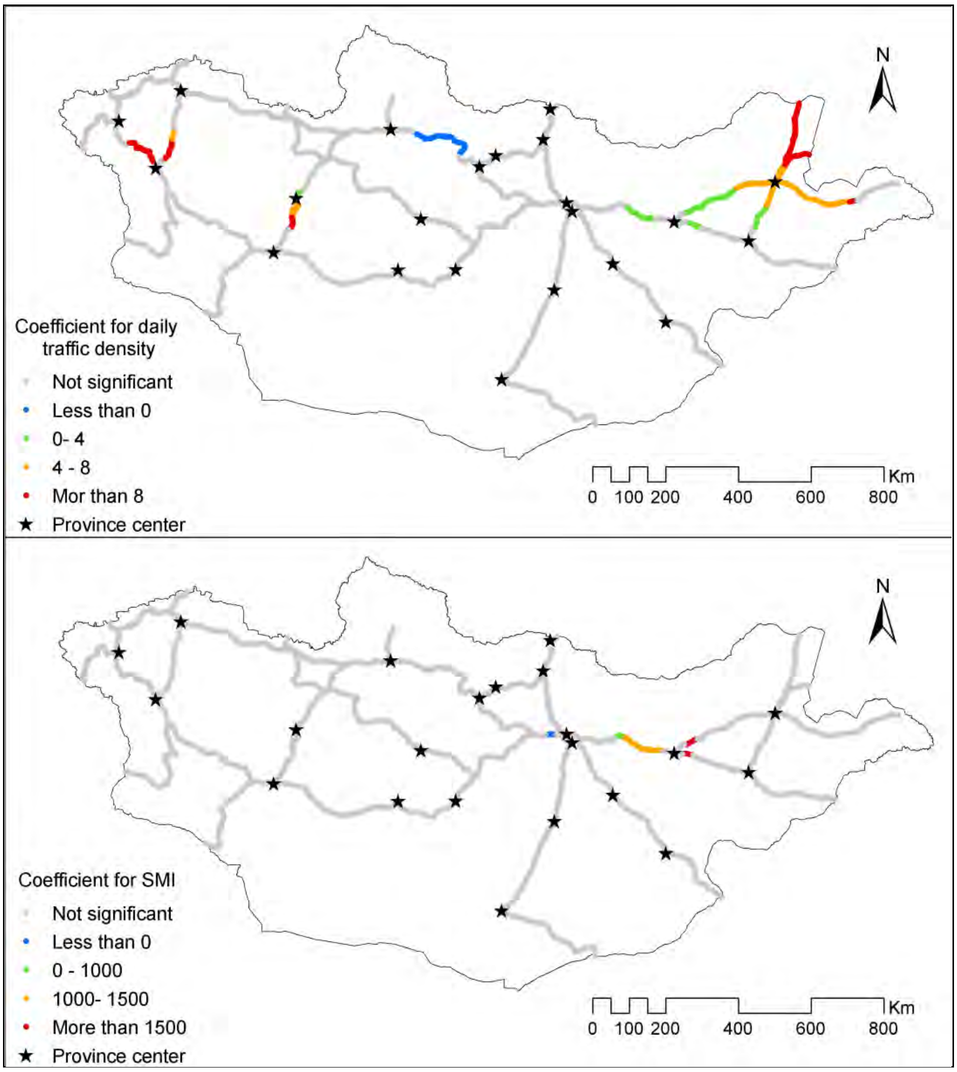


Figure 7.14: Influence of proximity to water features on corridor widths.

Road condition

Figure 7.15 shows that higher the traffic density, the more is the width, except where paved roads are already present. The more the proportion of light vehicles in the traffic, the more is the width, except when in combination with close proximity to a stream, where this effect is reversed, e.g. Bayanhongor and Arvayheer.



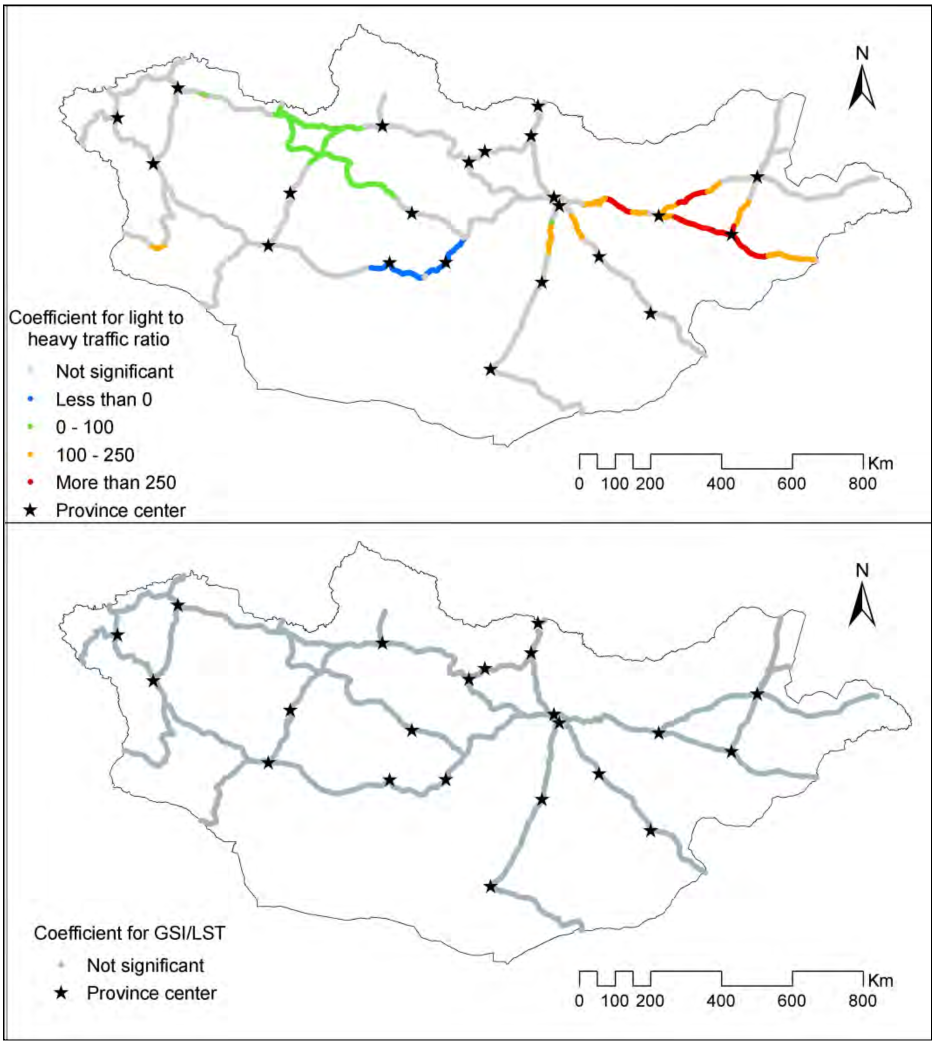


Figure 7.15: Influence of road condition parameters on corridor width.

The influence of SMI was significant in very small area and it was positive (the wetter the soil, the wider is the corridor). GWR results showed that GSI and LST were not locally significant, even though the OLS showed that it was significant. This shows that GSI and LST are global variables.

Vegetation

As anticipated, the MSAVI influence (Figure 7.16) was that the 'greener' area, i.e. the lusher the vegetation, the narrower is the corridor. Although scientifically we know that the low sparse vegetation means ‘vulnerable land’, the drivers appear to perceive it as ‘wasteland’.

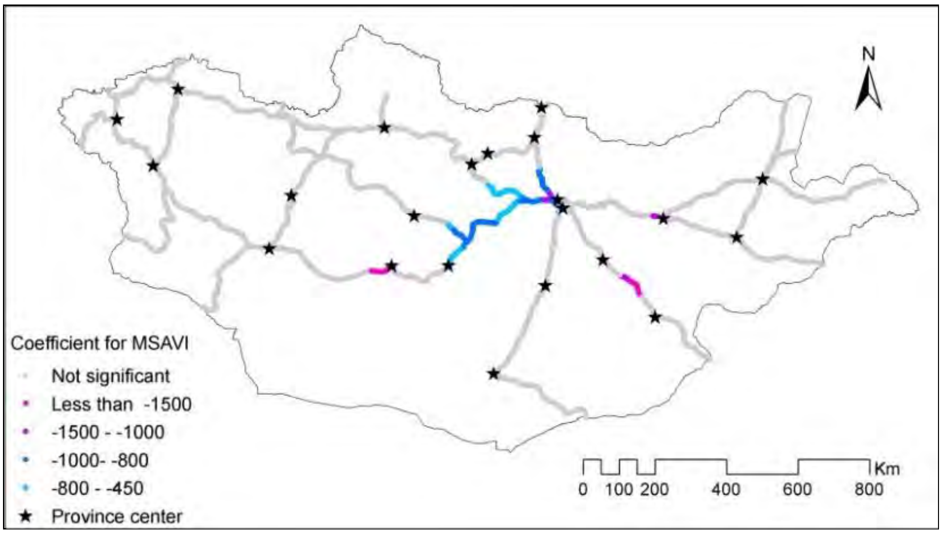


Figure 7.16: Influence of 'greenness' on corridor width for the studied routes.

7.4.2 Vulnerability models

As mentioned in section 7.3.2.2, after the statistical analysis identified the significant environmental variables, SMCA modelling was carried out to create a widening predictability map for Mongolia. The resultant maps of the expert based SMCA process are shown below. Figure 7.17 shows the resultant map of the SMCA model in which all criteria were grouped under themes; Figure 7.18 is without grouping of any of the criteria into themes; Figure 7.19 shows the output of model in which only the washboard related criteria were grouped under a theme. The table below each figure shows the accuracy of the model with respect to ground truth data verified using 100 randomly distributed sample points.

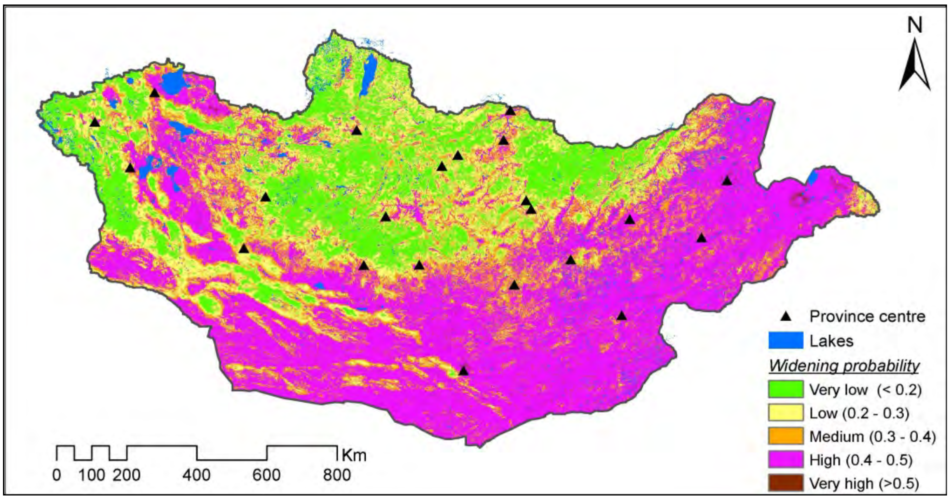


Figure 7.17: Resultant map of "All grouped" model.

The model of Figure 7.17 shows that almost 70% of Mongolia – the entire southern half almost, is highly prone to corridor widening. This definitely appears to be an overestimation, especially taken in light of the fact that it shows the northern area as almost totally not vulnerable. However, in the interests of objectivity, an accuracy assessment was carried out as explained in section 7.3.2.2. The results are placed in Table 7.5 and show that overall accuracy is about 51% at Kappa 37%.

All Grouped										
Observed\Modelled	Very Low	Low	Medium	High	Very High	correct total	Grand Total	Producer's accuracy	User's accuracy	Kappa(i)
Very Low	17	1	1	12	0	17	31	0.94	0.55	0.92
Low	1	14	10	3	0	14	28	0.88	0.50	0.83
Medium	0	1	2	18	0	2	21	0.13	0.10	-0.10
High	0	0	2	16	0	16	18	0.33	0.89	0.18
Very High	0	0	0	0	2	2	2	1.00	1.00	1.00
correct total	17	14	2	16	2	51				
Grand Total	18	16	15	49	2		100			
Overall Accuracy	51%									
Overall Kappa	37.12%									

Table 7.5: Accuracy assessment of the model 'All grouped'.

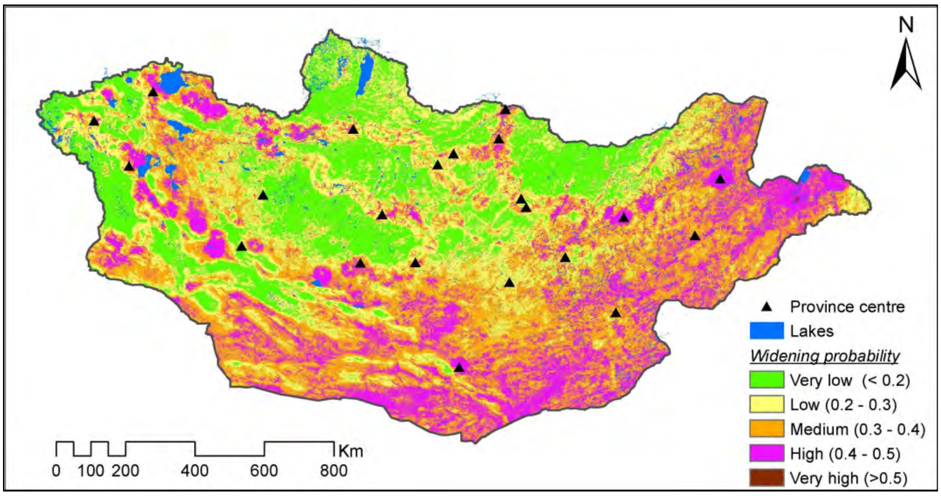


Figure 7.18: Resultant map of "No grouping" model.

The model output at Figure 7.18 appears to show much more credible results than the previous model. The accuracy assessment showed that the overall accuracy of this model is about 67% at kappa 56%, which is very good (Table 7.6).

No Group										
Observed\Modelled	Very Low	Low	Medium	High	Very High	correct total	Grand Total	Producer's accuracy	User's accuracy	Kappa(i)
Very Low	17	2	8	4	0	17	31	0.89	0.55	0.85
Low	2	23	0	3	0	23	28	0.77	0.82	0.68
Medium	0	2	18	1	0	18	21	0.53	0.86	0.40
High	0	3	8	7	0	7	18	0.47	0.39	0.35
Very High	0	0	0	0	2	2	2	1.00	1.00	1.00
correct total	17	23	18	7	2	67				
Grand Total	19	30	34	15	2		100			
Overall Accuracy	67%									
Overall Kappa	56.48%									

Table 7.6: Accuracy assessment of the model 'No grouping'.

Figure 7.19 shows the model output of the model Washboard grouped. Visually this model does not appear to particularly different from the model output at Figure 7.18, except in the eastern Steppes. However, the accuracy assessment showed that the accuracy of prediction is substantially improved over the other two models. Table 7.7 placed below the figure, shows that over 72% accuracy is reached at a kappa of 64%.

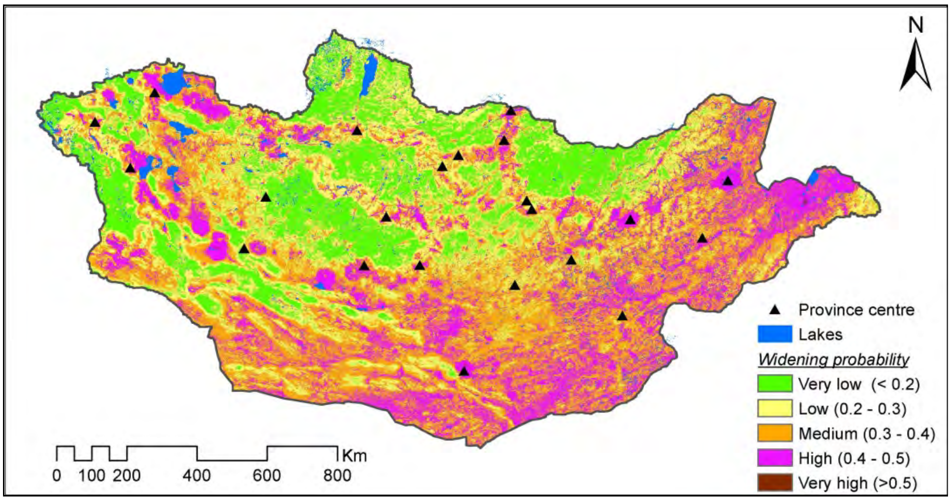


Figure 7.19: Resultant map of "Washboard grouped" model.

Washboard group										
Observed\Modelled	Very Low	Low	Medium	High	Very High	correct total	Grand Total	Producer's accuracy	User's accuracy	Kappa(i)
Very Low	15	3	7	6	0	15	31	1.00	0.48	1.00
Low	0	24	1	3	0	24	28	0.86	0.86	0.80
Medium	0	0	21	0	0	21	21	0.58	1.00	0.47
High	0	1	7	10	0	10	18	0.53	0.56	0.42
Very High	0	0	0	0	2	2	2	1.00	1.00	1.00
correct total	15	24	21	10	2	72				
Grand Total	15	28	36	19	2		100			
Overall Accuracy	72%									
Overall Kappa	63.40%									

Table 7.7: Accuracy assessment of the model 'Washboard grouped'.

The accuracy and kappa results are placed together in Table 7.8 for side-by-side comparison of the models' prediction quality.

Model	Overall accuracy	Kappa
All grouped	51%	37.12%
Ungrouped	67%	56.48%
Washboard grouped	72%	63.40%

Table 7.8: Model accuracy comparison.

As is seen in Table 7.8, the washboard-grouped model provided a significantly high accuracy of 72% (kappa 63.4%), much higher than the other two models, proving that it is more accurate in mimicking the road users' decision making processes.

7.5 Discussion

Due to the complexity and multiple methods used in conducting the research, this discussion is divided into:

1. Significance of methods
2. Implications of results
3. Utility of the study, and
4. Sources of error.

7.5.1 Significance of methods

It was found from the results of the statistical analysis that neither the influence of an environmental variable, nor its magnitude, is constant throughout the study area, but varies geographically. Not just lesser or greater influence, it may even have an inverted effect locally - It is the combination of circumstances (environmental parameters) that cause drivers to take the appropriate decision at the particular point in space and time, rather than a single parameter itself. For example, local inhabitants cite examples of how small discoveries of mineral deposits led miners to rapidly extract and truck the ore away, creating in the process, large dirt-track corridors that still scar the land several years after the mine is exhausted. It is also possible that a few tracks are purely 'desire paths'. These are exceptions that our model cannot cover, however it does address the general trend.

The vulnerability model derived from the statistically significant criteria made possible by use of geospatial datasets employs local user and expert knowledge to identify areas which would be vulnerable to degradation. The method is highly amenable to modification without any advanced knowledge required, and thus can be tweaked and fine-tuned by local engineers and planners, as needed. In fact it is expected that a seasonal tweaking would boost the utility of this model. Because it is a generic technique, it is also applicable by engineers and planners in other countries are regions affected by this highly deleterious phenomenon. The ease of use enhances its usability.

7.5.2 Implication of the results

Referring back to Figure 5.2 for specific locations, in the region east of Ondorhaan, the proximity to county center, proximity to river crossing, daily traffic density, light to heavy traffic ratio, and southern aspect influenced the dirt road propagation. In central regions, south and east of Ulaanbaatar, most of the considered environmental variables except MSAVI, GSI, and LST were significant. On the other hand, in west and north of Ulaanbaatar, the proximity to main rivers, river crossings, seasonal stream crossings, terrain slope, and MSAVI were significant. This could be because this region consists of the main river basins of Orkhon, Selenge and Tuul rivers and has quite a dense network of perennial water channels compared to the rest of the country. In the northern part of Khangay region and Khuvsgul region, proximity to province center, and lake, traffic density, light to heavy traffic ratio, and slope had influence on dirt road propagation, whereas, in the southern part of Khangay region, proximity to province and county centers, proximity to rivers, stream and their crossings, and lakes, light to heavy traffic ratio, MSAVI were significant. In Western Mongolia, traffic density, light to heavy traffic ratio, and proximity to stream crossing significantly influence the dirt road propagation.

7.5.3 Utility of this study

Given that a typical road development process takes between 10-15 years, especially over such large distances, we believe the results of this study can serve to urgently address the problem, increase social awareness and initiate mitigation measures. Senior managers and engineers in Mongolia were fully aware of the problem of environmental degradation due to dirt track propagation, but expressed helplessness at the situation. The completion of a paved road is seen as the only possible solution. However paved road of such massive length cannot be done instantaneously and will have to be implemented in sections. In such a case, the results of this study can be used to prioritise sections based on degraded widths. Directly, the wider the land degradation, the more urgent the ecological need to have a paved road; indirectly – the wider the degradation, the more are the stakeholders (road-users and pastoralists) affected by the negative effects of not having a paved road. Prioritisation of sections can be done by overlaying the proposed corridor alignment on the vulnerability map as seen in Figure 7.20.

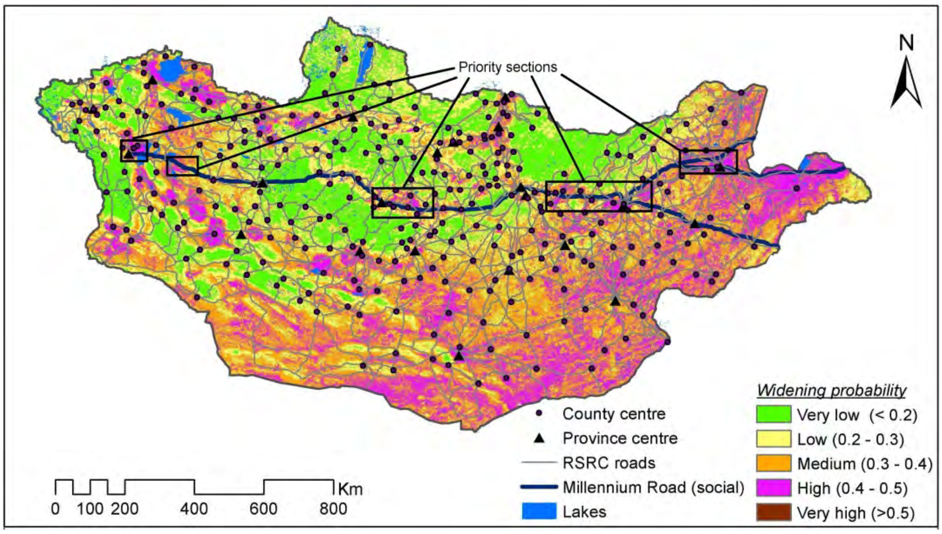


Figure 7.20: Prioritising sections of the Millennium Road based on usability and land degradation.

However, it is not possible to build paved roads 'everywhere' in a country of this size, either from the economic or ecological standpoint. We believe that by identifying and isolating the environmental factors that are leading to such driving behavior, we can help to initiate mitigation measures in the hotspot zones, by placing appropriately located low-cost corrective measures and aids. A few examples are marked on the map below (Figure 7.21) for illustration.

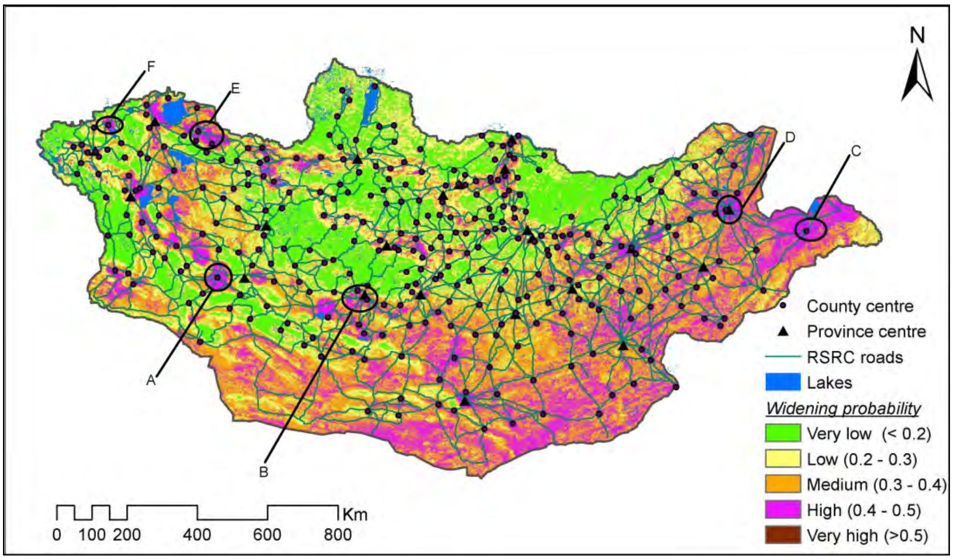


Figure 7.21: Identifying low cost mitigation/ countering measures

Some low-cost measures to remedy them could be formulated as in Table 7.9:

	Status	Remedial measure
A	Widening near this county centre	a ring road (not necessarily asphalted) on the periphery of the habited areas
B	Widening near this provincial centre	River-confluence: Direct river crossings by laying a low level Hume pipe causeway.
C	widening near this county centre	Constrict mining traffic to a limited corridor through monitoring
D	Widening near this provincial centre	A ring road (not necessarily asphalted) on the periphery of the habited areas
E	Widening in this area	Constrict mining traffic, hard path through sand dunes, signboards to border crossing and other arterial directions
F	Widening in marshy valleys	Signboards through marshy area, soil cement stabilisation

Table 7.9: Remedying and countering widening

The vulnerability map derived using the expert-based analytical model would also enable the prioritization of areas that need immediate and urgent attention across entire regions, by facilitating engineers of the RSRC the means to singularly locate their counter-measures. The model can be easily adapted for use in any other country afflicted by this dirt road propagation.

For example, in most of the country, there is a severe lack of bridges for crossing rivers, so drivers seek-out shallow stretches of river where they may cross. In order to reach this point, they first fan out, and then when they sight the river, narrow in again. If such behavior were understood, appropriate traffic information signboards/marker stones could be placed just before the fanning-out zone, to induce drivers to stay on one track. Such a measure would save the driver some aggravation and anxiety and also prevent environmental degradation. Another example of such mitigation measures would be by identification of areas that show characteristic signatures of waterlogged roads. In such stretches, the soil could be stabilized by 5-10% cement in the soil and graded thus enabling smoother travel and reduced degradation. Moreover, our analysis showed that near county centres, there is a sudden and drastic widening of corridors (Figure 7.21). This is due to drivers fanning out from the main trajectory as they branch out to go to their desired side of town, or start from a place in town and fan out searching for the main trajectory. A designated improved ring-road around the town, would serve the people within the town, as well as help to reduce the damage due to this practice (Figure 7.22).

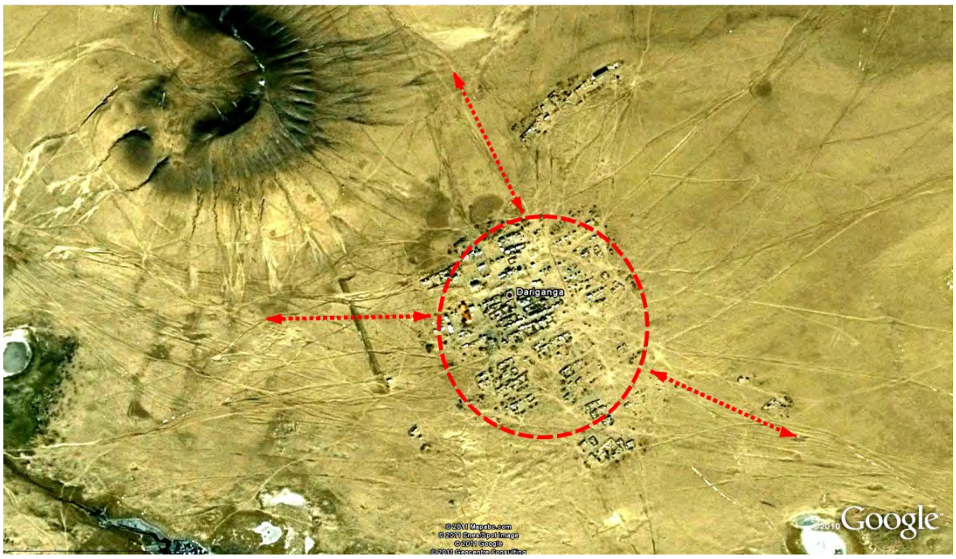


Figure 7.22: A ring-road around a county centre can reduce the land degradation considerably. (Source: Authors' elaboration on Google Earth image (Google, 2011c).)

Behavioural geography states that human activities which are the most routine can “warp” time and distance scales. This can be seen in the behavior of drivers. Drivers who use a certain route very frequently will often fail to realize that they have unconsciously cut across a bend in the tracks. Environmental constraining factors may often restrain them from doing so. However, if such factors don’t exist, human built interventions/reminders can be placed to guide the driver back to the path.

Many similar cost-effective remedies can be envisaged by local planners and engineers if the locations where they are needed can be identified quickly and easily. In addition to the identification of such low-cost remedies based on our findings, this study also seeks to highlight the problem, so as to create an awareness of it in the agendas of development agencies and development banks working in such countries, of the seriousness of such degradation and the urgency for counteraction.

7.5.4 Sources of error

This analysis had to deal with a temporal variability typically associated with a study at large spatio-temporal scale. Locations of topographic features such as main rivers, secondary rivers and lakes vary spatially, by season as well as over the years. Main rivers can meander, secondary rivers too can abandon the old course and choose a different course and, lakes and marshes can shrink in volume, thereby altering shorelines. Concurrently there is a seasonal variability in vegetation quality, soil moisture, snow cover on ground etc. thus there is a temporal influence on the corridor widths. We considered an analysis of the temporal variability of the tracks beyond the scope of this chapter.

The subjectivity in cognitive digitizing of the corridors also governs the accuracy of the digitized route polygons. Although a multi-stage quality control mechanism was established to ensure constancy of intent and procedure in order to reduce this error, there still remains the possibility of errors creeping in.

Perhaps the weakest link of our method is our use of Google Earth itself – a mosaic of images of a variety of indeterminate and unspecifiable resolution, seasonality and accuracy. Although Google does not provide an estimate of Google Earth's accuracy, Potere (2008) proved that overall horizontal accuracy for developing countries is about 44.4 m. These orders of accuracy for input data are acceptable given the extent of the local environmental variables, and site verification using GPS at several locations was done and found acceptable. Like other drivers who drive along these corridors, we too, when on site, could not see the full extent of the corridor width. Remote sensing, thus, is the most viable option for assessing the full extent, and within the constraints of our resources, we believe Google Earth was without doubt the best possible SDI-like resource available for this study.

7.5.5 Positioning with respect to the scale boundary object

This chapter consists of an amalgamation of 3 articles dealing with the environmental impact of not having a formal road infrastructure. The articles: 1) highlighting the problem, 2) attempting to understand the rationality behind it, and 3) using the understanding to identify and locate counter measures essentially dealt with the problem of dirt road corridors causing enormous rangeland degradation in arid and semi-arid regions of Mongolia.

Relating this to the boundary object of scale, the reader can identify the following explanations with the 3 axes.

The reality of spontaneous ‘highway’ formation by vehicle drivers – the human scale - “just one more track in this vast unused country”, contrasts sharply with the observation from a satellite – “wide swaths of degraded land, which act as easy channels for wind and water erosion and degradation of an entire biome”. The contrast shows how reality consists of a complex myriad of scales, whose effects are perceived very differently depending on the locus of the observer and the rationality – social, economic, ecological or political.

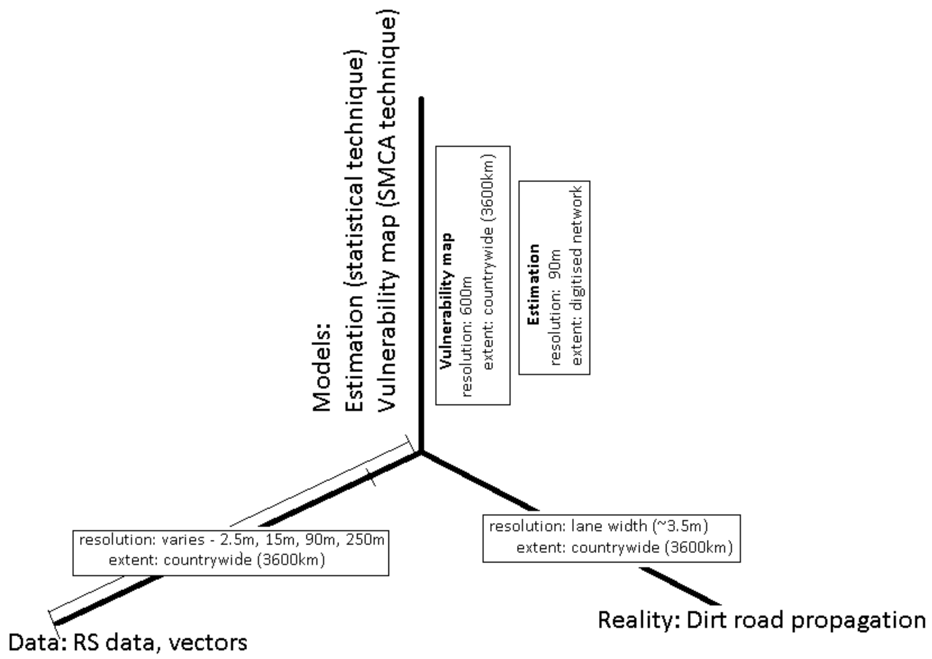


Figure 7.23: Positioning the case study

From the data point of view, the larger corridor widths are not perceived at the smaller, personal scale but recorded easily at the broader/coarser scale, whereas, smaller widths easier seen at the personal scale, are not visible unless fine resolution data (which loses sight of the overall picture) are used. Remote sensing and field collected data from different resolutions was resampled to 600m resolution and trimmed to national extent. Choice of data and data scale was governed by technical rationality.

Coming to statistical modelling, the poorer results from OLS, a global technique, compared to GWR, a locale-sensitive technique, showed that the effect of scale is seen in the modelling axes as well. The lack of strong relationship in OLS, led through a path of enquiry: Is there an appropriate scale (resolution) at which to study the relationship between width and environmental variables? If so, could it be a single scale or several nested and interrelated scales, or unrelated scales?

Correcting the OLS results for spatial auto-correlation to provide better R^2 was not a satisfying answer, as the marginal improvement in R^2 did not correspond to noticeably better correlation with facts as seen on ground. GWR, which can however, deal better with spatially varying relationships provided the logical outcome, showing how and where the various factors affect the driver behavior. However, GWR could only provide a model applicable to the roads studied, forcing me to question and reverse the very approach – use existing knowledge (which we use to verify the correctness of the statistical results) to model the solution countrywide.

The logic underlying SMCA and GWR techniques is similar, and amenable to the creation of a model at any scale. Although it may be seen that the SMCA approach takes an opposite view to understand the issue, it is actually not so - The two methods complement each other. SMCA is truly a transscalar technique that could use the findings of the GWR analysis to create a 'glocal model'. Hence the model scale issue did not play a dominant role in the final outcome. However, the choice of data scale (resolution particularly, but also extent) was a considered compromise between processing and storage capabilities on one side, and credibility and salience on the other side.

7.6 Conclusions and recommendations

The main conclusions that can be drawn from this study are that the driving behavior which leads to corridor widening is strongly related to local environmental variables, although as with all human behavior, subjectivity and individuality also play a role. Given that the issue can be rationalized, it is entirely possible to locate, identify and install appropriate mitigation measures or countermeasures to reduce the land degradation that is occurring unabated.

In addition to the mitigation measures, we also recommend the use of these findings in the design of the actual alignment of the real asphalt road thus following a user-centric approach, otherwise for many users, the “pull” of the environmental variables will be greater than the temptation to drive on a paved road, which was aligned as per a high level technical vision. We further recommend that more formal national spatial data infrastructure (NSDI) backed efforts should be made for assessing and regularly monitoring the phenomenon of dirt-track propagation. The creation, shifting and modification of these tracks could then be verified against the seasonal behavior of the rivers, streams, nomadic practices, ground cover etc. and be used to adjust mitigation measures.

The United Nations Convention to Combat Desertification (UNCCD, 2009) called upon the scientific community to identify technical ways to slow down the relentless desertification of entire landscapes. Arid and semi-arid rangelands are some of the most vulnerable landscapes facing the threat of desertification, and studies such as this answer the UNCCD call for action. The recent instance in China, of a herders-truckers conflict (Watts, 2011), show that with advancing desertification and increasing population, resources are getting scarcer thus the potential for serious conflict due to this phenomenon is getting higher. An awareness campaign to create more social consciousness amongst ‘road’-users, of the long-term implications of their actions on their environment is direly needed.

8 Synthesis

Recap, reporting, reflections and recommendations

Highlights

This chapter synthesises the findings of this research.

It will answer the research objectives in the context of sustainability and scale in the planning of highways.

Discussing the methodological aspects of the research and its applicability to the case studies demonstrated herein, as well as future cases, it will bring out the utility of the techniques demonstrated in this research.

Recommendation for improving planning in research, policy and practice are also made.

8.1 Introduction

This chapter aims to synthesize the key elements of this research in order to derive a general framework for a more rational planning of highway alignments. It will consist of four main components –

1. Recap of the preceding chapters.
2. Reporting on the research objectives and research findings.
3. Reflecting on the case studies and applicability of the demonstrated methodology.
4. Recommendations for research, policy and practice that can be drawn from this research.

8.2 Recap

Chapter 1 set stage for this research by introducing the arena to which research would contribute. A background review of literature in planning and assessment from scientific research and practice was conducted. The essentials of assessment processes such as SEA, EIA, CBA were explained showing their strengths, and identifying lacunae that need addressing. Taking examples from current planning and assessment practice in the Netherlands, UK, Mongolia and India, from the idealised and realistic perspectives, it was indicated how many of the alignment practices can be improved upon. The scene was set for a multi-tiered approach, which emulating an SEA methodology, would show how the case-studies of this research would be structured.

In Chapter 4, taking up from where Chapter 1 left off, a thorough and systematic review of scale related literature from the philosophical, theoretical as well as practical fields was carried out. An innovation, in the form of a 3-dimensional framework incorporating reality-study, models and data, was synthesised from contemporary knowledge to deal with the vexing issue of scale, which would help to integrate contemporary advances in scale related research. The concept of a boundary object, a flexible means of relating diverse views and disciplines while maintaining the core idea robustly was used to show how the issues of scale choices may be better understood, stated and negotiated in transdisciplinary discussions and contexts where the choice of scale cannot be readily apparent.

Chapter 4 studied the case of a very large-scale Greenfield [19] trans-national highway - the Millennium Road of Mongolia. At an enormous 3000+ km length, this highway is part of an even larger program – The development of the Asian Highway network. The routing of the highway presents an interesting plan structuring challenge. Being an international highway, it has stakeholders at the international level, but as every highway it will also affect people at the national level and local level for better or for worse. Using the device of a multi-tiered assessment-based planning method, it was shown that broad policy level developmental goals such as the MDGs can be addressed within a highway corridor alignment process along-side other more sub-national or supra-national criteria.

Chapter 6 demonstrated the case-study of the Via Baltica Expressway in north-eastern Poland. This expressway, considered a priority component of the transcontinental Trans-European Transport (TEN-T) network ran into stakeholder dissatisfaction on a regional 350km portion due to its non-transparent planning processes that had potential to cause severe ecological damage to some of Europe's oldest and best protected natural areas. Unlike the case study in Chapter 4, which showed the development of a Greenfield highway corridor, the Via Baltica planning case-study was methodologically challenged by an EU planning requirement which specified that the expressway should only be through a series of upgrades of existing highways, and no "new highways" were to be created. Through this case study the utility (and adaptability) of stakeholder-driven multi-criteria spatial analysis in achieving more sustainable highway solutions was again demonstrated.

Chapter 7 studied the issue of dirt roads in Mongolia. The lack of proper all-weather roads is spurring the formation of dirt-road corridors in this vast country with a sparse population. These dirt roads, some of them several kilometres wide pose serious and far-reaching consequence in terms of land-degradation and eventually desertification. Using satellite imagery from virtual globe Google Earth, as a cost and time-efficient way of assessment, we

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[19] A Greenfield project is defined as one which lacks any constraints imposed by the presence of prior work or pre-existing networks.

digitised and investigated the impact of these dirt-road corridors along the main national (and regional) vehicular arteries. The information along with other spatial information was used to generate an assessment 'surface' which can be used to locate hotspots and alleviate the problem by means of fine-scale low-cost/cost-effective interventions or be used to prioritise highway development and maintenance projects.

Through these three carefully selected real-life in-progress projects as case-studies the use of an impact-based route planning methodology at multiple geographical and analytical scale levels was demonstrated. The research allying itself to the principles used in a transport SEA, aimed to contribute to the improvement of the SEA process.

8.3 Reporting

The aim of this thesis was to provide deeper insight into a transparent methodology for assessment-based planning of highway alignments through different scales. The research niche for this study was formulated as: *'The formulation and assessment of sustainable optimal highway alignment alternatives through stakeholder based collaborative planning, which can operate in a multi-disciplinary, multi-scale context, and is enabled by contemporary spatial information technologies such as GIS and remote sensing.'* This goal was to be achieved through the use remote sensing technologies and geo-information tools, based on a transparent set of criteria, and addressing the various facets of scale related issues in the planning of sustainable linear infrastructure. To achieve the research goal five main objectives had been formulated:

<u>Objective 1:</u> To develop a framework on scale which can be used to scientifically understand, explain, negotiate and select scales in a transdisciplinary context.

<u>Objective 2:</u> To develop methods for providing appropriate information to decision making, that is information conforming to the three principles of credibility, salience and legitimacy.

<u>Objective 3:</u> To understand the highway planning process and contribute to meaningful utilisation of stakeholder input in highway planning processes at different spatial scales or planning tiers, without losing practicality.

Objective 4: To develop strategies and methods to aid transparent decision making in infrastructure planning through alternatives generated by incorporating stakeholder participation and good quality information.

Objective 5: To assess the dimensions of highway planning as an institutional management tool in development.

The conclusions of these objectives are reported here-below.

Objective 1: To develop a framework on scale which can be used to scientifically understand, explain, negotiate and select scales in a transdisciplinary context.

To fulfill this objective, a boundary object of a 3-dimensional framework was developed after compiling and combining contemporary research findings in scale. The framework consists of three axes forming three facets. The boundary object enables a user to think and express scale choice in terms of an understanding of reality, modelling reality, explaining reality, applying solutions back to reality along with the whole gamut of potential operations in between.

Objective 2: To develop methods for providing appropriate information to decision making, that is information conforming to the three principles of credibility, salience and legitimacy.

Primary data collection is the most time consuming part in many studies, investigations and censuses. Sampling strategies are developed to reduce time and cost of data collection. Similarly secondary data, maps, imagery, thematic data, may be very expensive and these costs may be prohibitive in assessments for institutions without appropriate budgets. The widespread apprehension of the high cost of spatial data is often considered one of the main reasons for non-use of spatial analysis. This apprehension was indeed well grounded in the early days of GIS. However, in recent years advances in remote sensing, image interpretation and GPS data availability have all but swept away this problem. In fact, there is a glut of data in the world today and a practitioner must often choose which data is most appropriate for the desired purpose.

Although high (spatial) resolution remote sensing imagery continues to be expensive both in terms of initial and processing costs, for uses in highway planning it is just not needed, and may even be counterproductive. Medium resolution imagery with more spectral bands provides the desired information with greater ease, for larger extents and without a need for excessive processing resources. Most importantly for many developing country practitioners, it is free and readily available. For example, the MODIS imagery used in Chapter 6 to derive soil moisture, grain size, NDVI, the SRTM-DEM for deriving important slope and elevation data in Chapter 4, and the DMSP-OLS night-time light imagery used to derive information about levels of economic activity in Chapter 6, are all free and readily available.

This research therefore found that remote sensing imagery can be used to significantly compensate for paucity of spatial data, a key necessity for good quality highway planning. It could also be firmly confirmed that natural areas vulnerable to ecosystem fragmentation can be identified and graded by combining established ecological indicators using remotely sensed data and GIS.

The second objective was to understand the highway planning process and contribute to meaningful utilisation of stakeholder input in highway planning processes. To fulfil this objective, an in-depth review of highway planning and assessment processes in various countries and institutions was conducted. A boundary object on scale was developed and demonstrated in Chapter 4 which can be used to scientifically understand, explain, negotiate and select scales in a transdisciplinary system consisting of reality, model and data dimensions.

Objective 3: To understand the highway planning process and contribute to meaningful utilisation of stakeholder input in highway planning processes at different spatial scales or planning tiers, without losing practicality.

The understanding of the issues of scale through the framework of the boundary object aided the development of techniques for highway planning demonstrated by case studies in Chapters 5, 6 and 7, which showed that it is possible to incorporate meaningful stakeholder inputs at different spatial scales and planning tiers, without losing sight of practicality. The tiers ranged from strategic policy level to tactical local level, wherein at each level stakeholder participation was incorporated by taking into account ecological, social and economic rationalities using spatial multi-criteria decision support techniques.

<u>Objective 4:</u> *To develop strategies and methods to aid transparent decision making in infrastructure planning through alternatives generated by incorporating stakeholder participation and good quality information.*

Methods that provide quantitative and spatially explicit results can aid and enhance transparent decision making and increase utility of the intervention were developed and demonstrated, showing that the use of spatial decision support tools can enable more environmentally friendly planning if carried out with sufficient rigor and impartiality.

<u>Objective 5:</u> *To assess the dimensions of highway planning as an institutional management tool in development.*

The final research objective consisted of assessing the potential of highways as an institutional management instrument through the use of strategic planning of the alignment. This objective was mainly taken up in Chapter 4 and demonstrated a technique for planning a highway corridor that can incorporate socio-economic policy level goals such as the MDGs in the route alignment process, thus allowing the highway to be used as a focused management instrument in development.

Through the utility obtained from remotely sensed information it was also demonstrated that spatial decision support tools can bring added value to the highway corridor planning process without considerable increase needed in institutional capabilities.

8.4 Reflection

Today's highway infrastructure planning is an enormous challenge. It wasn't always so – the bulk of road systems in many of the world's most developed countries were mainly built in the 'pre-ecological era' ((Forman, 2003)), an era before assessment and planning professionals in those countries began understanding the long-term cumulative, permeating impacts of rife road development. Forman and Alexander (1998), revealing the complex knit of scales of the reality of road ecology call for planning that can unravel the complexity and weave it into a "*tapestry of theory and application".*

Developing countries now vie for amenities, ease and therefrom, the luxuries that developed countries enjoy due to their well-developed transportation systems, particularly highways. In their haste to have such infrastructure speedily, many fail to fathom the enormous long term losses that the developed countries incurred. They also fail to notice the awareness of ecological loss dawning over the West and how planners in the most 'enlightened' countries are trying hard to return land occupied by infrastructure back to nature, even if it means subjecting road users to the squeeze of reduced amenities (for example, odd-laning of existing roads, road-use pricing, polluter-pays taxation, increased car parking fees etc.). Others are looking at merging and melding of infrastructure for example, multimodal transport, multi-functional use of space, context sensitive design. Yet others initiate paradigm shifts in the very principles of infrastructure planning for example '*green infrastructure'*.

The issues facing developing countries are of course quite different from those faced by developed countries, with observations on the "*tyrannies of distance and isolation*" (Wang et al., 2009, World Bank, 1999) still uppermost on their agendas, while decision makers and researchers of the developed world talk about "death of distance" (Black and Nijkamp, 2005). Knowles (2006) however tempers this claim by acknowledging that successive transport innovations have resulted in *differential collapse in time and space* for societies and individuals, particularly over the last 50 years, with some regions (and countries) more collapsed than others. He calls for transport geographers to apply their intellectual efforts to evening-out the differences. This research applies progress in planning approaches that are being brought about in developed countries to hold just as true for developing nations.

Ideally planning should follow a tiered structure with decisions from one level are passed on to the next higher or lower planning level, but with the exception of a handful of countries this is rarely the case. This is where procedures such as SEA become useful in obtaining proper and consistent outcomes – it forces proponents to think and use tiering in planning and implementation. The three underlying principles of SEA are transparency, good implementation and public participation. The exercise of these principles can be divided into 'carrot' and 'stick' approaches. For the 'willing' (i.e. voluntary), SEA is a 'carrot' – a tool that improves planning with stronger connections to environmental assessment, so that the assessment is ex-ante. The other side is the ‘stick’ – SEA processes mandated by the law to ensure a minimum guarantee that alternatives will be generated, and decisions taken, in a transparent, tiered manner with public participation at all levels.

Making SEA mandatory doesn’t always encourage good practices, as proponents will follow the processes dictated by the regulations only with a barebones’ view to conforming to them. However, voluntary SEA can immensely improve planning. A country example is the Netherlands, which has been following SEA-like tiered planning processes long before the EU’s SEA Directive came into force (Kooiman and Keshkamat, 2011). Additionally, SEA should be seen as transparent knowledge –

- For the decision makers, towards informed decision making,
- For the implementers, for informed planning and implementation, and,
- For the stakeholders, towards timely, relevant and credible information about the processes.

The methodological development of this research has been based on this principle – the voluntary betterment of current highway planning practices through the incorporation of techniques that would enable better informed participation, planning and decision making. It will also be realised that planning which followed such an approach would make it easier for processes to conform to the regulatory ‘stick’, while at the same time easing planning and assessment processes for practitioners.

8.4.1 Reflection on methodological aspects with respect to scale

Scale was regarded as one of the key issues in this research. This section will reflect on the conclusions of the case study using the boundary object presented in Chapter 4. It is placed here again (Figure 8.1), for reference to the discussion which will relate to the 3 facets of the boundary object. As many environmental and economic processes and patterns are scale dependant, planning and assessment practice should necessarily consider it from the interest of credibility salience and legitimacy. However, earth system processes’ scales are usually trans-scalar by nature and hence very complex and difficult to model. To complicate their understanding further, most processes in reality and their attribute characteristics are interwoven both in spatial as well as temporal dimensions. As described in Chapter 4, when we seek to understand them in research, or implement interventions in practice, we identify '*observation windows*' – what is chosen to be observed, interpreted, planned or managed. The 'what' includes spatial characteristics, temporal characteristics and/or relevant attributes and responses over space and time. In order to do so, we usually assume for our understanding that scales are 'lumpy' and discrete (Wilbanks, 2008). Scales in social concerns are somewhat easier to understand in comparison – they can be lumped into administrative or geographical regions which can be nested although some anomalies may arise (Herb and Kaplan, 1999).In terms of analytical and planning processes hierarchies come into play (Mintzberg, 2000, Saaty, 1988). However, the choice of scale decides which stakeholders' views will be taken into account.

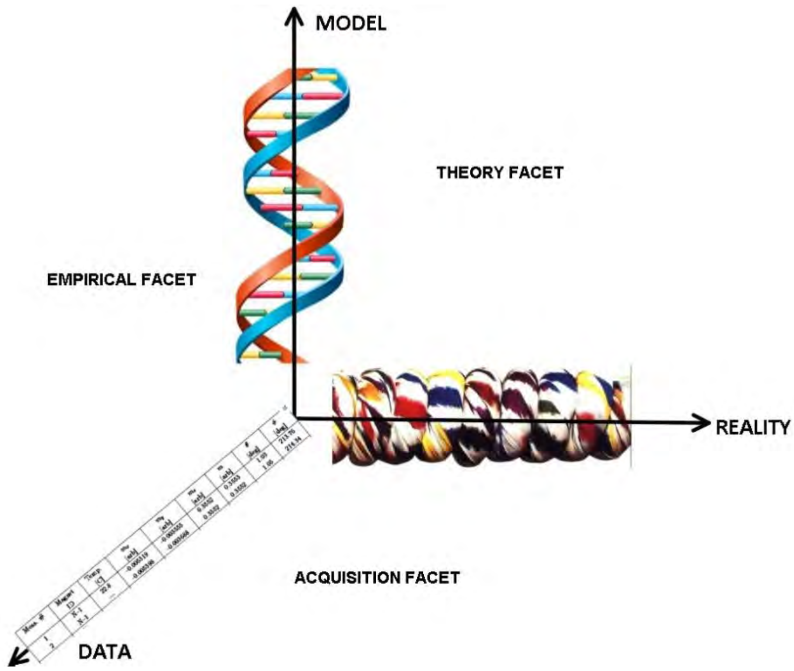

Figure 8.1: Understanding scale selection using a 3D framework boundary object

This research takes the line that the process of scale selection and planning needs to be based on the issues to be addressed, first and foremost. In this research, four planning levels in the highway planning hierarchical process were considered. As seen in Table 8.2 within each of these levels the issues to be addressed require the identification of a particular pair of extent and resolution for the reality, models and data. Given the importance of scale, and implicitly, time-period (Refer Figure 4.5), at the start of Chapter 3, the distinction was drawn between the concepts of level (tiers) and scales.

The connection of this research purely to spatial scale is highly tenuous, and claim is not made otherwise. The key line of reasoning taken in this research is that there are many different scales, spatial, temporal, data, societal, institutional, and even (most importantly) the scales in mindsets of stakeholders as mentioned by Herb and Kaplan (1999). As per Meentemeyer (1989), Thill (2011) the spatial context in GIS involving the behavioural geography is relative, rather than absolute. This is the reason why the connecting thread of this research is how to deal with issues at different planning and assessment levels and the core backbone through which this connecting thread is supported, is the tiered planning system. This kind of planning system, and the interactions within it, has been little researched even though SEA tries to force proponents to do so. The boundary object presented in Chapter 4 allows, and aids, this line of reasoning. It allows transformational scales in relative space, such as that existing in reality, to be used in conjunction with models and data, which usually have Euclidean foundations and use the concept of absolute space.

With respect to the modelling dimension, the multi-criteria analysis technique used in this thesis is trans-scalar, and by itself, is amenable to use at any scale without issues. Furthermore, because of the processes of standardisation and weighting built into it, it forms the bridge between the relative space in the mind-sets of stakeholders and the absolute scale of usual GIS data. Thus, the highly versatile tool of SMCA simplified the selection of scale in the models of this research. However, the technique can only be used in one scale at a time, because through the weighting process, the effect of scale enters the model. The same set of stakeholders can give different priority weights to criteria when asked to think at different levels. For example, in the criterion "*proximity to productive pasture land*", most farmers/herders wish for the highway to run as close to their pasture when thinking at a sub-national scale, as they keep in mind the benefits of being able to get their products to markets as easily as possible. Accordingly they consider the criterion a benefit and give it high weightage. However, when asked to consider the same criteria at a local (county scale), the NIMBY syndrome (Not-In-My-Back-Yard - Brion (1987)) comes into effect and the criterion's nature jack-knifes from benefit to burden and its weight changes (Diener, 2011). Thus, the SMCA analysis technique, although it can be used at any scale is, in practice essentially multi-scalar, not trans-scalar. Therefore, although it is a simple and easy-to-use technique, it should be used with caution in order that outcomes are credible and legitimate.

Scale also comes into play in the modelling aspect from the issues of complexity, which is directly related to the resolution of the model. Some modellers believe that the model definition and outputs get better if many aspects are included in the model and focus on improving methods that can take into account the complexity, for example Waidringer (2001), Snowling and Kramer (2001) and Janssens (2006). Others such as Pidd (1996, 1999), Salt (1993) and Arthur et al. (1999) criticise this, observing that increasing model complexity does not necessarily add to its quality, but may actually diminish the accuracy and applicability of its results due the cumulative effect of errors from its many individual variables. Koelle et al. (1997), Pidd (1999) and Lindenschmidt (2006) in fact argue that there is a trade-off between model complexity and accuracy after a certain point. Chwif et al. (2000) recommend that during preliminary runs of the model, the number of variables (criteria) be kept to a limited number of factors of known data quality, and in subsequent iterations more variables be added, in a cautious and informed manner. This philosophy is also echoed in the AHP process pairwise comparison module in most multi-criteria software, wherein the number of criteria is limited to 15, i.e. about 100 possible combinations, in order to ensure "*faithfulness of ranking*" (Saaty, 1987). Hence the appropriate level of complexity (i.e. model resolution) needs to be used.

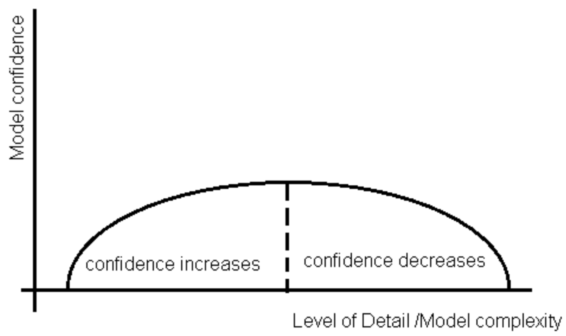

Figure 8.2: Relation of model complexity to confidence (Adapted from: Chwif (2000))

In addition to the effect of weightage of the criteria, the scale of the data itself plays an important role in the outcomes of the analysis. Scale of data, particularly resolution, is usually a trade-off between managerial rationalities such as cost, processing capability, storage capability and man-hours needed to gather it, versus the scientific or technical requirements. (However, citizens' privacy and security issues may also play a role in data availability and use sometimes.) In general, it was found that at higher planning tiers, the goals are broader and hence coarser data is more appropriate (Bourgeron et al., 1999, Iverson Nassauer and Corry, 2004, Kienast et al., 2009).

Even if data at high resolution is readily and freely available, a decision on whether to use it as-is or coarsen it by resampling should be taken, because high resolution data may not represent the properties of the entity as a whole. For example, assessing grassland degradation (in Chapter 7) due to dirt track propagation from a high (sub-meter) resolution image is much more difficult than that from a 15m resolution ASTER image because there is such a large variation between reflectance values of the many pixels that comprise the area of a single corridor, that becomes difficult to identify the extent of the corridor.

The case-studies of this research reflect this philosophy – at the higher level planning (Chapter 5), a data resolution of 2km was found sufficient and appropriate, whereas for route finding within the Via Baltica case (in Chapter 6), a resolution of 1000m was chosen based on the effect distance of the highway, while a resolution of 90m was chosen in Chapter 7 due to the need to consider highly local criteria such as earth-track muddiness, that would influence the driver to widen-out between one 2km segment polygon and the next. It should be noted that the resolution choice being discussed here is in the order of magnitude rather than a specific discrete number - the actual precise number will be based on the common denominator of all datasets used in the SMCA.

8.4.2 Reflection on alternatives in highway planning and assessment

The important role that transparent, rationally-generated route alternatives play in the planning and sustainability of highways cannot be overstated. It imparts legitimacy to the planning process and increases stakeholder participation in the planning process. Indirectly it empowers local communities. By giving them a say in a development that could deeply influence their future for better or worse, it inculcates in them the sense of ownership of public works and instils social inclusion. In participatory planning, intimate local knowledge, considered an essential requirement for the highway planner even in current practice, would come from the collective rather than an individual perspective thus further bettering the outcomes. The ability of the method to include highly technical criteria at all stages in the planning process, further aid the credibility of the generated outcomes. In addition, the outputs of the method are comparable with each other, qualitatively as well as quasi-quantitatively in a consistent manner. Thus decision makers get condensed targeted information that they need for informed decision-making.

The alternatives can be based on visions (scenarios) that are generated collectively and negotiated decision making occurs at each step in the planning/procedural hierarchy. However, there are some drawbacks. Even though the strength of this this type of tiered planning is that there is total transparency in how the alternatives were developed, there will always be reason for discord – theoretically at least, the possibility exists that alternatives developed at lower levels (i.e. later stages in the planning hierarchy) do not fit within the spatial extent of the alternatives devised and chosen at higher levels. This is surely true in the case of a top-down approach, but it is also relevant in a bottom-up approach, where several piece-meal alternatives developed at lower levels may not plug together to form a consistent whole, thus causing the implementation of entire plan to fall through. There will always be a conflict of interest, whether the bottom-up or top-down approach is chosen. One size does not fit all - this conclusion is inescapable. However, it is in this aspect also that the flexibility of this methodology serves well, because the alternatives that are generated can be expressed, negotiated and scientifically tweaked, or easily regenerated, as per the course of stakeholder discussions and compromises, without significant loss of planning effort.

Table 8.1 shows IAIA's SEA performance evaluation criteria. Based on the descriptions from previous chapters and sections, it can be seen how closely the planning processes and outcomes proposed in this research shadow an ideal SEA process. Adopting this approach would therefore help to conform to statutory assessment procedures, thus highlighting the utility of this method to assessment and planning practitioners. Sanchez and Silva-Sanchez (2008) have shown with the example of the Brazilian Rodoanel highway how using a voluntary SEA process in the planning of the highway eased the process of environmental approvals.

Is integrated	• Ensures an appropriate environmental assessment of all strategic decisions relevant for the achievement of sustainable development. • Addresses biophysical, social and economic interrelationships. • Is tiered to policies in relevant sectors and (transboundary) regions and, where appropriate, to project EIA and decision making.
Is led by sustainability	• Facilitates identification of development options and alternative proposals that are more sustainable.
Is focused	• Provides sufficient, reliable and usable information for development planning and decision making. • Concentrates on key issues of sustainable development. • Customized to the characteristics of the decision making process. • Is cost- and time-effective.
Is accountable	• Conducted with professionalism, rigor, impartiality and balance. • Is subject to independent checks and verification • Documents and justifies how sustainability issues were taken into account in decision making.
Is participative	• Informs and involves interested and affected public and government bodies throughout the decision making process. • Explicitly addresses their inputs and concerns in documentation and decision making. • Has clear, easily-understood information requirements and ensures sufficient access to all relevant information.
Is iterative	• Ensures availability of the assessment results early enough to influence the decision making process and inspire future planning. • Provides sufficient information on the actual impacts of implementing a strategic decision, to judge whether this decision should be amended and to provide a basis for future decisions.

Table 8.1: IAIA's SEA Performance criteria (IAIA, 2002)

8.4.3 Reflection on improving sustainability in highway planning

In recent years, with the growing competition for natural resources and economic growth, there are very few developmental or research initiatives that do not include the term '*sustainable*' in their description and aims (Bell and Morse, 2008). Sustainable development has indeed become "*the watchword for international aid agencies, the jargon of development planners, the theme of conferences and learned papers, and the slogan of developmental and environmental activists.*" Lele (1991) observes succinctly. And although at the Earth summit at Rio, the Brundtland Commission coined what has become the most often-quoted definition of sustainable development as development that "*meets the needs of the present without compromising the ability of future generations to meet their own needs*", Fortune and Hughes (1997) amongst others observe that the term is "*an empty concept, lacking firm substance and containing embedded ideological positions that are even with the best interpretations, condescending and paternalistic*". But "*everyone agrees that it's a good thing*", say Allen and Hoekstra (1993).

Like others, we too used the phrases "*planning for more sustainable development*" and *"sustainable alternatives"* often in this research, and find it obligatory to explain why we feel they were not loosely used, even though the increase in sustainability by using the method (tiered, assessment-based stakeholder-inclusive planning approach) in this research cannot be quite quantified. Sustainability comes into the highway development life-cycle in four main forms:

1. Sustainable planning/ design
2. Sustainable construction
3. Sustainable operation/use
4. Sustainable decommissioning

Although all four forms are essentially inter-related, this research aimed to contribute particularly to sustainable planning. Figure 8.3 laying the context shows the main thrusts behind our use of the phrases through the use of a Venn diagram, with the three pillars of sustainability – the social environment, the biophysical environment and economics as the main sets of stakeholder perspectives. The intersection areas of the perspectives show the type of development that can be aimed for. Development intended for socially inclusive growth can only be achieved if the social and economic perspectives are brought together, while addressing only social concerns without ecological conservation considerations could lead to a community that rapidly becomes unliveable. Similarly in order to have viable growth, both ecological as well as economic concerns need to be considered. We believe that only when perspectives from all three spheres are brought together can there be “sustainable growth” – growth that is potentially bearable, viable and equitable at the same time. [20]

The arrows on the peripheries of the circles in Figure 8.3 are a metaphor for the efforts we need to put in to maximise bearability, equitability, viability, and ultimately, sustainability of the development. In this research, the efforts recommended were procedural (stakeholder participation), technological (geospatial and engineering knowledge) and methodological (use of tiered processes from policy, planning and assessment practice).

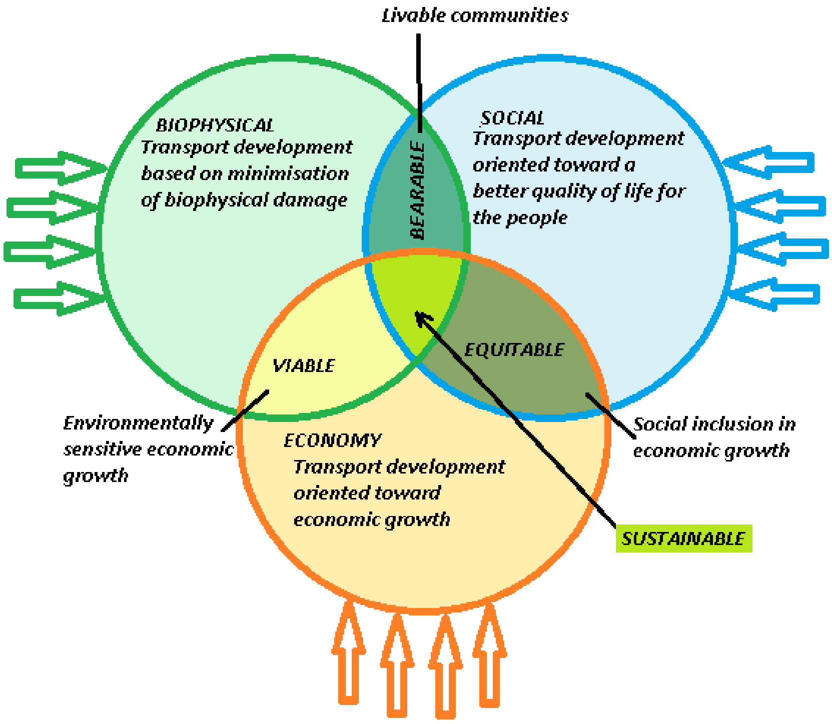

Figure 8.3: Sustainable development, showing the principles behind this research.

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[20] To bring this precisely into the spirit of the Bruntland Commission definition in a practicable manner, two more dimensions need to be considered - the temporal dimension and the institutional dimension.

The ideal scenario is of course that there is 100% intersection between all sets, and that all perspectives are at the same time socially, ecologically, economically inclusive and sustainable. But we know that this is not possible – the laws of entropy tell us that for every gain there must be some loss - every intervention that we impose upon the environment will have some negative impact. However, by maximising the intersection areas, a metaphor for maximising corresponding stakeholder consensus in the planning, we can minimise the negative impacts and increase the sustainable characteristics of the intervention.

Three relevant questions need to be asked before sustainability can be operationalised:

1. For what spatial extent is it aimed to be sustainable?
2. For what time period is it aimed to be sustainable?
3. For which specific issues is it aimed to be sustainable?

We did not deal explicitly with temporal aspects in the case-studies mentioned in this dissertation; however, spatial extent and specific issues are shown in Table 8.2 and temporal periods are assumed to be implicitly linked to spatial extents and issues.

Case study	Tier	Spatial extent	Specific issues
Chapter 3	Policy and Plan	National, in supranational context	Social accessibility, economic connectivity, techno-commercial feasibility, Ecological viability.
Chapter 6	Plans and programmes	Subnational	Social safety and connectivity Economic utility techno-commercial feasibility, Ecological preservation.
Chapter 7	Programmes and Projects	National, in local context	Social safety and connectivity Economic loss prevention Ecological preservation.

Table 8.2: Sustainability aspects of the case studies

Through the incorporation of stakeholder perspectives, concerns and priorities in a tiered alignment mechanism that dealt with different scales (geographical and temporal) we aimed to show how the net sustainability of a highway development can be improved on social, ecological or economic fronts.

8.5 Recommendations

8.5.1 Scale selection in highway planning

The need for guidelines related to scale choice has been made by Joao (2000), Partidario (2007) and many others. Karstens (2009) in her research framed guidelines for scale selection in policy analysis processes in water management where there are multi-stakeholder perspectives and multi-disciplinary factors. O'Niell et al. (1995, 1996) have reported that in reporting landscape patterns, the grain size should be 2 to 5 times smaller than spatial feature of interest. Goodchild (2011) also makes a recommendation that resolution is inversely proportional to extent, based on the data processing perspective. Thus, it will be seen, as mentioned in Chapter 4, that there is no 'right' or 'wrong' choice of scale, only an appropriate choice of scale, and preferably a negotiated one. Based on this research, the some guidelines for scale choice can be formulated.

At the start of the study the issues of the study should be separated into 3 distinct phases - Reality, model data - based on the approach intended to analyse the study-problem. Then the goals of the study under each phase and the constraints likely to be faced in each of the three phases should be identified. These can be separated in terms of required extent and resolution for each of the 6 rationalities – technical, economic, social, ecological, legal and political.

Based on this it is possible to identify convergences and conflicts of scale. Amongst the ones which conflict, the scale choices 'fixed' by the law (legal rationality) will necessarily be decisive. Scale choices due to other rationalities can/should be negotiated with the understanding that there always needs to be a trade-off:

c) Between resolution and extent,
d) Between interactions within each facet, and
e) Between different facets.

Additionally, there may be strategic considerations by powerful stakeholders or proponents. As will be clear from this research, scale selection is not a one-off process for a whole highway planning exercise from policy to projects, but must be carried out iteratively at each tier.

8.5.2 Suggestions for further research

During the course of this research the need was felt for some objective techniques that would have added greater value and objectivity to this methodology. These included:

- Methods for identifying affected stakeholders by conducting a spatio-temporal analysis of ecosystem-services likely to be affected. If such an appropriately usable technique existed, this would have been a much more objective method of stakeholder identification compared to a subjective identification as is usually done (also in this thesis).
- A method for transport infrastructure planning and assessment based on convergence, coexistence and competition of different modal networks – roads, rail, pipelines, airways, marine and river waterways, data and energy transmission systems, canals, ecological corridors.
- A method for assessment of traffic density on regional network links using remotely sensed night-time light imagery and spatial interaction models, such as gravity and diffusion modelling, on networks. In this research it was easy to find recent and good quality traffic density data. This is not always the case, especially in large developing countries. It is believed that night-time light imagery, which has been proven to be correlated strongly with economic activity, can be used to predict/estimate traffic density on the links connecting different economic centres with a sufficient accuracy.
- A method for identification of locations of mitigation measures such as wildlife crossings based on terrain impedance as perceived by key indicator species. An effort along these lines was tried by us on the A9 highway in Limburg, The Netherlands, but more effort is needed to make it viable and easy to use.
- Object based image analysis (OBIA) that could have been suitable to identify and vectorise dirt roads from remote sensing imagery. As it exists today OBIA could not cope with the heterogeneity of the different factors involved in the detection of dirt tracks over large areas.

Although efforts were made to research these alongside the key objectives specified in this thesis, most of them are immensely complex concepts and did not bear useful outputs with the limited efforts. Their development, however, could strongly aid the planning methods proposed in this thesis and, as such, these ideas bear value for future efforts in this research agenda.

8.6 Closing remarks

Although not very common, incorporating environmental impacts into projects while they are still being planned does occur in highway planning. These voluntary design inputs are usually so rare as to go unrecorded and unsung, in a discipline that has traditionally stayed engineering-focussed. Making strategic environmental assessment mandatory can indeed ensure that environmental concerns will be taken seriously in the planning process, but as in any discipline, the efforts of the willing are far more effective than those meant solely for compliance with regulations.

If planning processes can be evolved so that consideration of environmental criteria, transparency and stakeholder engagement will be afforded the same emphasis and rigour that conventional engineering stages (such as pavement structural design based on axle load calculations, or horizontal, vertical and transition curve design) are allocated, the highways we develop could have much greater sustainability than they are currently imbued with. This desirable evolution could be fostered by:

- Sensitising highway planners and engineers to the concepts of social and environmental capital, equity and constrains (Hollick, 1981),
- Encouraging a closer knit between assessment and planning in education as well as practice (Palmer, 1998), and,
- Developing predictive, evaluative and design tools that can objectively account for environmental and social considerations in the planning process (McDonald and Brown, 1995).

It was the aim of this research to be a proactive part of the evolution of planning processes towards more sustainable highway systems.

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Summary

Highway route alignment is usually a consistently grey area in highway planning practice. Although much progress has been achieved in detailed engineering design of pavements and road geometrics, current techniques of highway route planning suffer from some shortcomings - most miss a full-fledged use of the impacts in the planning process. Often much of the planning isn't spatial by nature, and so fails to understand the issue of scale in planning. It is also often argued that impact assessment of highways usually occurs too late in the highway development process and therefore can only mitigate, and almost never avoid serious negative impacts or enhance positive impacts. Also, conventional impact assessment is focussed on negative impacts only, and is thus seen as an imbalanced obtrusive compulsion by proponents.

If the assessment processes are pulled upstream of the planning process, geospatial techniques (such as GIS) and geospatial technologies (such as remote sensing) can improve, and even ease, the process of highway alignment. It would also allow the bringing of stakeholder engagement processes early into the planning, thus saving much time in the later stages, reducing implementation delays and boosting the sustainability (social, environmental, economic and political) of the development. Strategic Environmental Assessment (SEA) processes encourage such improvements.

However sustainability is strongly scale-dependent, and so the issues of scale also need to be given strategic thought in the development of the planning process from the viewpoint of the credibility, salience and legitimacy of the planning process and its outcomes. Yet, despite copious amounts of research on it, it still remains largely un-understood and is underutilized in the planning and assessment processes. We do so through the use of a 3-dimensional framework which is flexible enough to apply to across different disciplines and yet robust enough maintain the core ideas, offer a means to do so. It enables the understanding and negotiation of highway planning scale issues from the perspective of analytical tiers, reality scales, model scales and data scales.

By applying the principle of strategic thinking to the planning process, a multi-tiered route alignment methodology is used to understand and identify what should be the goals and stakeholders considered in the planning of a highway

at different scales. Multi-criteria analysis aided by spatial information and GIS forms one of the main techniques used in this research to understand and incorporate diverse stakeholder opinion, concerns and priorities into the decision support process of the formulation of alignment alternatives. It is tailored to specific applications by combining with other GIS and remote sensing techniques.

From the perspectives of sustainability and techno-commercial feasibility, it is as important to consider local, provincial, national goals as well as international ones in the planning of international highways. There is also a temporal aspect - long term as well as short-term goals need to be incorporated, and hence the multi-tier planning system should be able to accommodate goals from policies, plans, programmes as well as projects.

At the highest planning level, the outcomes of the planning process would be corridors which are aligned to broad policy goals. In middle tiers these corridors will be used to limit and identify route alternatives; and in lower tiers, to prioritize projects and implement mitigation measures. Thus, positive impacts can be maximized and negative impacts can be minimized at each tier and stakeholders at each level will have been heard in a transparent manner.

This research proposed a methodology for planning of sustainable mega-highways through different geographic and administrative scales and through four tiers in tiered planning structure. It encourages consideration of both positive and negative impacts in the planning of large highways and therefore encourages objective and more transparent practices in highway planning practice. By bettering the practice and outcomes of the planning process, stakeholder satisfaction, environmental protection and economic benefits from the projects can be increased.

Samenvatting

Binnen het vakgebied infrastructuurplanning wordt het generen van corridor – en routealternatieven doorgaans gezien als een tamelijk grijs gebied. Hoewel er veel vooruitgang is geboekt in het wegbouwkundige planning en ontwerp, kennen de huidige technieken van corridor- en routeplanning een flink aantal tekortkomingen. Zo zijn deze technieken vaak niet ruimtelijk, waardoor het probleem van schaal in planning niet onderkend wordt. Daarnaast worden effecten (zowel negatieve en positieve) van routealternatieven niet direct meegenomen in de planning procedure. Als gevolg hiervan gebeurt het bepalen van effecten van infrastructuur meestal op een laat moment in het ontwikkelingsproces gedaan en kunnen zodoende serieuze negatieve invloeden alleen maar worden gemitigeerd, maar niet worden vermeden. Ook zijn deze procedures vaak uitsluitend gericht op he inzichtelijk maken van negatieve effecten, en wordt daardoor gezien als opdringerige compulsie van de tegenstanders.

Geografische informatiesystemen (bijv. GIS) en technieken (bijv. RS) kunnen het proces van corridor- en routeplanning verbeteren, zelfs vergemakkelijken als effectenprocedures verder aan het begin van het planning proces plaatsvinden. Hierdoor kunnen belanghebbenden ook vroeger in het planningsproces betrokken worden, wat veel tijd kan sparen in latere stadia van het planningsproces. Hierdoor kunnen vertraging en frustratie in de uitvoering vermeden worden en duurzaamheid (sociaal, milieu, economisch en politiek) van de ontwikkeling worden gevorderd.

Duurzaamheid is echter sterk schaalafhankelijk, waardoor het aspect 'schaal' strategisch overwogen moet worden in de ontwikkeling van het planningsproces – zeker als gekeken wordt naar aspecten van geloofwaardigheid, salience, en wettigheid van het gehele planning proces en de resultaten hiervan. Ondanks uitgebreid onderzoek, blijft schaal toch nog steeds een grotendeels onbegrepen en onderbenut aspect binnen het planning en assessment proces. In dit onderzoek wordt een 3-dimensionaal raamwerk voorgesteld, dat flexibel genoeg is om te passen binnen verschillende disciplines, en toch robuust genoeg om aan de kernideeën van ??? vast te houden. Dit raamwerk stelt ons in staat om de rol van schaal in de planning van infrastructuur beter te begrijpen, vanuit een perspectief van realiteit, model en data.

Een strategische effectenanalyse wordt gebruikt om doelen en stakeholders binnen verschillende schalen van het infrastructuur planningsproces te bepalen.

Multi-criteria analyse, geholpen door ruimtelijke informatie en GIS, vormt een van de voornaamste technieken in dit onderzoek om verschillende meningen, belangen en prioriteiten van stakeholders te kunnen begrijpen en op te nemen in het besluitvormingsproces voor de formulering van corridor- en routealternatieven. Het is op maat gemaakt voor specifieke applicaties door middel van de combinatie van GIS en RS technieken.

Zowel vanuit het perspectief van duurzaamheid als techno-commerciële haalbaarheid is het belangrijk om lokale, provinciale, nationale en internationale doelstellingen te overwegen tijdens de planning van infrastructuur. Tegelijkertijd bestaat er ook een temporeel aspect; korte- en lange-termijn doelen moeten geïntegreerd worden, en hiervoor moet het voorgestelde meervoudige planningsysteem doeleinden betreffend beleid, planen, programma's en projecten kunnen accommoderen.

Op het hoogste niveau van infrastructuurplanning zijn er de resultaten van het planningsproces van de corridors, afgestemd op relatief brede beleidsdoelstellingen. In de middenlagen van het planningsproces worden deze corridors gebruikt om alternatieve routen te identificeren en selecteren; terwijl op het laagste niveau het stellen van project prioriteiten en het implementeren van 'mitigatie' maatregelen centraal staat. Zodoende kunnen, op alle drie lagen – hoog, midden en laag – zowel positieve invloeden gemaximeerd, en negatieve invloeden geminimeerd worden. Ook zijn stakeholders op elk niveau op een transparante manier in het proces geïntegreerd.

Dit onderzoek stelt een holistische methodologie voor, voor de planning van infrastructuur (waaronder continentale snelwegen) door verschillende geografische en administratieve schalen, en door de vier lagen van een strategische effectenanalyse. Het moedigt aan om zowel positieve als ook negatieve invloeden in de planning van grote snelwegen te overwegen, en daardoor ook objectieve en transparantere praktijken in het infrastructuurplanningsproces. Zodoende kunnen stakeholdertevredenheid, milieubescherming en economische voordelen verhoogd worden.

Curriculum Vitae

Sukhad Keshkamat, born 28th April 1974 in Goa - India, is a graduate civil engineer with about 15 years of experience in the field of civil engineering, particularly construction project management of large infrastructure. He did his schooling at the St. Xavier's High School, Ahmedabad and Bachelors in Engineering (Civil) from the Birla Engineering College, Vallabh Vidyanagar in Gujarat state. In 1995, he graduated ranked second in the university and was awarded gold medals in concrete technology, prestressed concrete, environmental design of buildings and remote sensing.

After graduating, he moved actively into the field of project engineering and has earned a reputation for his versatile project management experience in a variety of construction projects ranging from sprawling luxury hotels to shipbuilding dry-docks, and from 'clean-room' pharmaceutical industries to construction of highways and bridges. He also has substantial experience in structural designing of RCC and steel, real estate valuation and construction contracting.

In late-2005, he left his managerial position at the Goa State Infrastructure Development Corporation for his postgraduate studies in Geo-information for environmental modelling and management specialising in regional transport planning, at the universities of Southampton, Lund, Warsaw and ITC under the Erasmus Mundus programme of the European Union. In late-2007, he was awarded the ITC Research Scholarship to conduct this PhD research study. He co-supervised the research of 8 MSc students during his PhD studies.

He is an active member of the Institution of Engineers-India (IEI), Indian Concrete Institute (ICI), Indian Institute of Bridge Engineers (IIBE), Indian Roads Congress (IRC), International Ferrocement Network, Infra Eco Network Europe (IENE), International Association of Impact Assessment (IAIA), International Association of Mathematical Geosciences (IAMG), International Geospatial Society (IGS) and a few sustainability science forums. He has been awarded a silver medal and an honorary life membership of the Institution of Engineers' (India) for his achievements. An engineer who ardently believes in the philosophy of *jugaad*, when not on the beach or backpacking, he spends much of his leisure in fixing and DIYing electronics, electrical and mechanical items for self, friends and charities. A detailed professional CV can be seen at http://www.linkedin.com/in/sukhad

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