Chapter 6

A Framework for Identifying and Qualifying Uncertainty in Policy Making: The Case of Intelligent Transport Systems

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6.1 Setting the Scene

There is increasing concern about the impact of uncertainty in policy making. Policy decisions often do not lead to the realization of policy aims and may even cause adverse impacts, and such developments seem to be occurring more frequently in recent times. There are various reasons for this situation. The world subject to policy making is becoming increasingly complex and fast changing. We mention the quick advancement in new technologies, the integration of the global economy, the increased environmental burden of economic activities, and the increased differentiation in needs and interests between categories of the population. Particularly the growing awareness of stakeholders about their (power) position in pursuing their interests and swift changes in these positions make the design and implementation of policies inherently more complex. Accordingly, policy decisions are made without a full understanding of the present situations and developments, and this is even more true for the future. For this reason, in rational models of policy making an extensive use of decision support tools and methods is suggested, like cost-benefit analysis, risk assessment, and more advanced computerized support tools. However, although policy makers are aware of various kinds of uncertainty, little attention has been paid to a systematic approach in the identification and evaluation of uncertainty. Only a few policy studies consider the comprehensive character of uncertainty in policy making in view of improved decisions (see, for example, van Asselt, 2000; Funtowicz and Ravetz, 1990; van Geenhuizen and Thissen, 2002; Khisty and Arslan, 2005; Walker et al., 2003).

Uncertainty is particularly evident in the field of policy making on future transport and communication technology (for example, van Geenhuizen et al., 1998; Geels and Smit, 2000). This situation stems from the fact that transport is a derived activity and the transport system is interconnected with a range of widely different other systems of, for example, production and consumption, living and
working and recreation. The transport system also comprises various subsystems such as infrastructures and vehicles (for example, car, rail and plane), and various (sub)systems according to the geographical scale. In addition, there are high costs involved in supporting the introduction of new transport technology (for example, hydrogen-fuelled vehicles and a concomitant fuelling infrastructure, advanced driver assistance systems, and magnetic levitation trains), but the demand reactions of consumers, reduction of road congestion and environmental burden and the emergence of unwanted side-effects, are poorly predictable (for example, van Geenhuizen and Nijkamp, 2003). Since the impacts of present policy options are poorly predictable, any choice made may lead to failure. What then is a wise course to follow in selecting the technologies to be supported, the strategies to test and improve these technologies, and the instruments to advance market introduction once the technology is mature?

Uncertainty is difficult to define because it touches upon many different aspects. Uncertainty in a broad sense refers to all we do not know and all we do not know to a full extent (for example, Rowe, 1994; Wynne, 1992). Rowe (1994) in a broad approach elaborates uncertainty as the ‘absence of information’ and makes a division into four related dimensions, that is, concerning: 1) the past and future states of the system under study; 2) the quality of the models that represent reality and are used in explanation and prediction; 3) the quality of measurement of the model relations, and so on, in reality, including issues like precision and accuracy (validity); and 4) communication and interpretation of results of analysis and modelling in a policy context. The first three dimensions comply to a large extent with what is termed ‘model uncertainty’ and its causes (see Section 6.2). It needs to be mentioned that the term risk is closely related with uncertainty. Risk may refer to specific situations in which the behaviour of the system under study is basically well known and chances of different outcomes can be defined and quantified by an analysis of mechanisms and probabilities, whereas in most uncertainty the system behaviour is not well known (for example, Wynne, 1992). We consider risk as a sub-set of the much broader set of uncertainties.

Instead of adopting a broad perspective on uncertainty, attention in policy making may be limited to those missing elements of knowledge that matter in taking the right decisions. This holds for the system being studied and subject to policy measures, including unexpected behaviour of stakeholders. Uncertainty may therefore be defined as the gap between what we know and what we think we need to know in policy making. In practice, uncertainty is not an objective phenomenon; what is perceived as uncertainty is dependent upon the satisfaction with existing knowledge and this is ‘coloured’ by various underlying values and perspectives, and the specific context (for example, Khisty and Arslan, 2005; Stough and Rietveld, 1997).

The purpose of this chapter is to develop a broad framework to identify various types and sources of uncertainty that surround policies on new transport technology and ways in which different types of uncertainty can be handled. Further, we apply our framework to the case of intelligent transport systems and evaluate the results in the context of a larger applicability. Accordingly, we perceive influence diagnostic sufficient situations; uncertain under-
perceive new transport technology in a multi-actor situation by recognizing the influence of different stakeholders and their fast-changing positions. Our diagnostic framework is expected to match the following design rules: 1) to be sufficiently generic to serve a broad range of policy making situations in transport and similar complicated systems and to be adaptable to specific technology situations; 2) to be sufficiently comprehensive to cover a large variation of uncertainty aspects, and 3) to yield a sufficient transparency to improve understanding of different sources of uncertainty and to select the best mix of ways of dealing with uncertainty (see Walker et al., 2003). This leads to a focus on:

- the factors and system behaviour about which uncertainty exists
- the nature of this uncertainty in terms of sources and severity of impacts on policy making
- the ways to deal with uncertainty.

These aspects will be discussed in a theoretical way in the next two sections, and this is followed by an application to intelligent transport systems.

6.2 Conceptual Framework and Classes of Uncertainty

In our approach to identify uncertainty, we make the assumption that policy makers contemplate policy choices referring to a specific part of reality and that their decisions are based on means-ends rationality. This implies that policy makers are looking for knowledge that enables them to select those interventions that will contribute most to bringing policy goals nearer. In our attempt to structure uncertainty, the relevant part of reality may be conceptualized as a simplified system (Figure 6.1). The system model represents the set of cause-effects relationships characteristic of the behaviour of a system. A critical decision in this conceptualization is the definition of the system’s boundaries. This decision determines the framing of issues and formulation of problems (for example, broad or narrow), particularly the identification of external factors that influence the problem and the scope of alternatives considered.

We distinguish two broad types of factors as an input to the system, that is, external factors and policy factors. External factors may significantly impact on the system but are beyond the control of the policymaker. Policy factors are those factors through which a policymaker can influence the system. We may also distinguish output factors; these indicate those characteristics of the system performance that represent wanted and also unwanted outcomes, and, accordingly, are considered relevant criteria for the evaluation of the success of policy measures (van Geenhuizen and Thissen, 2002).
Figure 6.1 A system-based policy framework to identify uncertainty

The conceptualization described above provides various classes of factors that potentially cause relevant uncertainty (Figure 6.1): 1) the boundaries of the system; 2) future relevant external inputs; 3) system properties and performance and system responses to the various inputs; and 4) valuation of policy results based on a set of values. These different classes of uncertainty lead to an 'overall' uncertainty in making the right policy choices. We present details about the relevant uncertainty and sources of uncertainty as follows (van Geenhuizen and Thissen, 2002; van Geenhuizen et al., 2003; Walker et al., 2003):

1) Ambiguity in the definition of the system's boundaries may lead to an unclear framing of issues and formulation of problems. Stakeholders often have different perceptions of reality, related to their different views of the world and their different interests. If important stakeholders are excluded from defining what the issue is, policy makers will then develop a biased framing of the context and system view, potentially leading to confusion, delay and ultimately additional uncertainty in policy outcomes. The same holds true for the view on external factors. If the system is defined too narrowly, particular factors that might be influenced by the policy concerned are seen as external and beyond control.

2) Uncertainty about future external inputs includes those factors considered to be beyond the control of policymakers. Factors beyond control in the field of transport may significantly influence the system, such as dead-ends in technology research and diminishing economic growth determining shrinkage of public budgets for research and, maybe – depending on how the boundaries are drawn – urban sprawl of living and working causing a thinning of traffic flow to different degrees on different geographical scales. Policies from other departments that are beyond control of transport...
policy, like those in spatial planning, may also be viewed as external factors (for example, Friend and Hickling, 1997).

3) Uncertainty about *system properties and performance in terms of response to external inputs* can have different causes, most of which relate to a lack of an adequate theory about system behaviour and to problems with the specification of empirical values, given a theory. System behaviour in this context refers to transport systems. As expectations about system behaviour are generally based upon a model of the system, uncertainty in this respect is often termed *model uncertainty*. It refers mainly to the nature of the impacts of transport policy (and of lack of such policy) and to the irreversibility and scale of such impacts. There are three major causes of model uncertainty. First, there is uncertainty about the relevant model components and the key relations that determine system behaviour, termed *structural uncertainty* by Rowe (1994). Secondly, given model components and relations, there may be uncertainty in the exact specifications of these relations. In modelling terms, this is called *parameter uncertainty*. Particular mechanisms, mainly unknown to date, may lead to unpredictable results due to non-linear and irregular (chaotic) behaviour. In addition, the lack of appropriate data can be an important cause of model uncertainty, referred to by Rowe (1994) as *metrical uncertainty*. Further, what might happen is that a policy (project) is not feasible based on model outcomes but that, nevertheless, a positive policy decision is taken, due to specific interpretations of the outcomes and other data, for example, demand estimations and assessments of costs. This is an example of what Rowe (1994) refers to as *translational uncertainty*. Large projects in transport infrastructure that are subject to cost overrun and remarkably optimistic traffic forecasts illustrate this particular type of uncertainty. The often large differences between forecast and actual costs and demand cannot be explained primarily by structural and metrical uncertainty. By being strongly consistent and one-sided the uncertainty that has entered follows from the strategic behaviour of stakeholders.

4) Uncertainty about the *valuation of the policy outputs* is mainly concerned with the importance given to (future) system outcomes based on different value sets. It makes sense to distinguish between core values that are relatively stable over time and norms and standards at lower levels of abstraction. What causes uncertainty is a weak link between core values and practical standards, such as that between freedom and responsibility of individuals to drive their own vehicle as a core value and standards relating to a certain degree of central guidance concerning driving vehicles; this situation leads to confusion about what should, and what should not, be respected. In addition, in a multi-actor situation, there is pressure on norms and standards from different sides of stakeholders, sometimes leading to unexpected shifts in norms and standards in the evaluation of policy outcomes.
Uncertainty in valuation of policy outcomes contributes to uncertainty in making the right policy decisions. In fact, all previously indicated uncertainty contributes to uncertainty in making the right policy choices that could influence the system (policy factors), potentially leading to not achieving the intended effects. For example, uncertainty in the coordination of liaisons, in setting the agenda, and in taking policy measures may be caused by ambiguity in the delineation of the system and uncertainty in system properties and performance (Friend and Hickling, 1997).

We will now briefly address the severity issue. It is difficult in general to assess which of the above classes of uncertainty is most worrisome in a policy making context, because the context may vary from situation to situation. It can be stated that, in general, apart from ignorance (Dror, 1988), the most serious forms of uncertainty are the external influences beyond control and structural uncertainty about the system itself. The reason is that these uncertainties may have the greatest impacts in terms of expected policy outcomes that are wrong, while relatively little can be done to reduce their influence without strong research efforts (and high investments). Dealing with uncertainty will be discussed in more detail in the next section.

6.3 Dealing with Uncertainty by Policy Makers

There are different strategies to deal with the types of uncertainty described above and these may vary between governments depending on their wish to be involved to certain degrees and to bear risks, and depending on the type of prevailing uncertainty. The strategies listed below may not exclude other; some of them are in fact complementary and depend on each other (van Geenhuizen et al., 1998; van Geenhuizen and Thissen, 2002):

- To ignore uncertainty, take policy measures and see what will happen. In fact, this means accepting the risk of great uncertainty in policy outcomes and serious policy failures by the wrong (or incomplete) selection of measures.
- To identify and, if possible, specify uncertainty. This enables the policy maker to act consciously in the presence of uncertainty, mainly uncertainty about future external factors and system performance response to these factors. Methods to identify and specify uncertainties include, for example, scenario analysis (van der Heijden et al., 2002; Nijkamp et al., 1997; von Reibnitz, 1998; Schwartz, 1991), case-based reasoning using retrospective analysis on past failures and success (Khattak and Kanafani, 1996), and sensitivity analysis using the development of alternative system models.
- To reduce uncertainty. Like the previous strategy, this mainly applies to uncertainty from external factors and related system performance responses. First, a reduction of uncertainty can be achieved by additional research and/or a better integration of existing knowledge. Additional research may use advanced methods such as chaos theory and modeling between possible events and both external factors with stakeholder and strategies. To accept uncertainty can lead to different strategies of uncertainty to be expected to do something and adaptive policy to the future, for example, Walther monitoring of advanced technology.
- To see uncertainty as a strategy holds and to make choices. Rather than an option, this approach provides the grounded with experiments.

We now move on to intelligent transport systems and uncertainty in this part.

6.4 Intelligent Transport Systems

6.4.1 Introduction

Intelligent Transport Systems (ITS) aim to smooth traffic flow, provide travel information (navigation) systems, and control vehicles. We limit our focus on intelligent vehicles (AGV), and the potential benefits for the adoption of this technology. We have found that due to the assumed potential reduction of the environment, example, Bekiaris and Marchau, 2002; I.

There is a wide variety of such systems and others are...
research may cover improved data collection and the application of advanced methods of integrated modelling, using notions derived from chaos theory and evolutionary models (Reggiani and Nijkamp, 2002). Note that modelling results enable the policy maker to distinguish more clearly between possible and impossible developments, and to identify critical events and bottlenecks (exploratory modelling). Also, uncertainty about external factors and system performance may be reduced by negotiating with stakeholders whose behaviour is uncertain.

- To accept uncertainty and act consciously in its presence. Here, too, different strategies are possible, and these can be applied to all major classes of uncertainty. A robust policy may be selected, that is, a policy expected to do well in most possible future circumstances. Or, a flexible or adaptive policy can be designed, such as a policy (choice) that is adaptable to the future course of events or new valuations of such events (for example, Walker et al., 2001). The latter policy requires an extensive monitoring of system behaviour and policy outcomes.

- To see uncertainty as an opportunity to creatively shape the future. This strategy holds mainly for the overall uncertainty in making the right policy choices. Rather than emphasizing a choice for a presently available policy option, this approach calls for the development of a broad vision that provides the guiding principles for present and future action, allowing for experimentation and small-step learning (for example, Stacey, 1992).

We now move our attention to uncertainty in policy making relating to intelligent transport systems, and apply our framework to identify and qualify uncertainty in this particular area.

6.4 Intelligent Transport Systems

6.4.1 Introduction

Intelligent Transport Systems (ITS) is a broad category of innovative systems that aim to smooth traffic flow and differences in density. ITS include advanced traveller information systems in public transport and private cars, route guiding (navigation) systems, advanced tracing systems of goods and automated guidance of vehicles. We limit our discussion here to the subclass of automated guided vehicles (AGV), and focus on uncertainties that are of concern in policy making for the adoption of this technology. The technology is attracting increased attention due to the assumed improvement of traffic flow, avoiding of congestion, and reduction of the environmental burden and numbers (severity) of accidents (for example, Bekiaris and Stevens, 2005; Bose and Ioannou, 2003; van der Heijden and Marchau, 2002; Ioannou, 1997; Lu et al., 2005 and Marchau et al., 2000).

There is a wide variety of AGV systems: some are quite similar to current systems and others are entirely different and surrounded by a manifold uncertainty.
In this context, it is useful to distinguish between various technology dimensions and positions. These technology dimensions are the nature of the drivers' tasks, the type of drivers' support, and the degree of mixing with established transport systems (for example, Levine and Underwood, 1996; Lu et al., 2005 and Marchau et al., 2000). With regard to the first dimension, the drivers' tasks, a distinction can be made between vehicle control (speed and direction), manoeuvre control (lateral and longitudinal positioning vis-à-vis other vehicles) and route control (navigation). The second dimension – type and degree of drivers' support – refers to the use of information to support drivers' decisions (warning, advising), automated control of a limited number of tasks, including the possibility for drivers to overrule this control and autonomous automated control without drivers' interference. With regard to the third dimension – the degree of mix – there is the theoretical possibility of a totally integrated implementation of AGV technology in particular regions, but also of different mixes with current systems, for example, limited to highways or even to specific lanes on highways. The more comprehensive the guiding system and the greater the differences with the current situation, the greater the uncertainty. For example, semi-automated vehicles equipped with forward-looking sensors are expected to be deployed in the near future, but less is known about the introduction of more advanced and complicated intelligence in vehicles and infrastructures.

There are quite high expectations about AGVs. These are supposed to increase transport efficiency and to improve the quality of the environment (Nijkamp et al., 1996). Traffic management systems and new types of cruise control (distance control) improve the efficiency of the flow of goods and persons. Efficiency gains contribute to a reduction of congestion and to a reduction of fuel consumption and emission per unit of goods and persons. Furthermore, new driver systems, such as collision warning systems, automatic speed adaptation and the comprehensive personal auto-pilot including the function of monitoring drivers' behaviour, are expected to contribute to the prevention of fatalities or reduce the severity of accidents (Lu et al., 2005 and Marchau et al., 2004). Systems in which equipped vehicles are grouped to move automatically may also contribute to the reduction of emissions and to a decrease in the use of energy. However, efficiency gains in terms of road use seem to be the largest benefits from this use of intelligence in vehicles and infrastructures. In the next part of this section we analyse uncertainties in the adoption of AGV including indications of the severity of the uncertainty concerned. A summary is given in Table 6.1.

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**Table 6.1**

<table>
<thead>
<tr>
<th>Class of uncertain System Boundary</th>
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<tr>
<td>Future External Inputs (beyond control)</td>
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<tr>
<th>System Performance and Response</th>
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<td>Valuation Policy Outputs</td>
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**Notes:** 
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Table 6.1 Uncertainties of relevance to policy making for AGV

<table>
<thead>
<tr>
<th>Class of uncertainty</th>
<th>Specification of uncertainty</th>
<th>Sources of uncertainty</th>
<th>Severity*</th>
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<tbody>
<tr>
<td>System Boundaries</td>
<td>- Unclear problem definition</td>
<td>Lack of knowledge</td>
<td>X</td>
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<td></td>
<td>- Fragmented or wrong problem view and view on causalities</td>
<td>Desire to 'keep things simple'</td>
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<td></td>
<td>- Inherent complexity of transport system and subsystems, and relations with other systems</td>
<td>Inherent poor predictability of most of these factors in the long term</td>
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<tr>
<td>Future External Inputs (beyond control)</td>
<td>- Changing needs and attitudes in driving and travel behaviour</td>
<td>Long-term nature of implementation of AGV</td>
<td>XX</td>
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<td></td>
<td>- Influence of the legal system (liability)</td>
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<td></td>
<td>- Future urban sprawl</td>
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<td>- Future technology</td>
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<td>- Future culture</td>
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<tr>
<td>System Performance and Responses</td>
<td>- Impacts of AGV on traffic safety, emissions and efficiency</td>
<td>Poorly-known key relations and mechanisms determining system behaviour, due to: lack of research with an integrated approach and focus on causality; lack of a clear specification of the structure of AGV in practice</td>
<td>XX</td>
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<td>- Interference of AGV with other transport goals</td>
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<td>- Type and time of indirect impacts (for example, in residential areas)</td>
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<td>Valuation of Policy Outputs</td>
<td>- No clear vision on which core values need to be respected</td>
<td>Passive role and ignorance of policy makers Occurrence of disasters that work as a 'catalyst' Long-term nature of implementation of AGV</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>- Shifting values and standards in judging policy impacts</td>
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Notes: * X = medium severity, XX = great severity.
6.4.2 Uncertainties

We first consider uncertainties related to the choice of system boundaries. It is important to note that changes in one part of the transport system may impact on other parts or (sub)systems. If the various relations between the subsystems within the transport system (that is, infrastructure, vehicle movements, persons and goods transported, and spatial and temporal configurations of living and working activity) are disregarded, unexpected policy outcomes may be the result. Changes, such as new intelligence in the vehicle subsystem, may directly and indirectly affect all subsystems and their stakeholders, ranging from driving behaviour on roads to decisions of the population on (re)location of places of residence. It is unclear what the direct effects of implementing certain technologies will be, and uncertainty is increased because changes in one subsystem of the transport system may have impacts throughout the system. There is little insight so far regarding these indirect effects, not least because they occur in different subsystems with diverse time-lags. In addition, there may be unexpected but undesirable effects, such as adverse consequences for safety or the attraction of more traffic, which undo the direct reduction in environmental impacts. This situation illustrates the crucial importance of drawing adequate system boundaries.

With regard to relevant external inputs beyond the control of transport policymakers, we identify unknown developments in human needs and attitudes in driving and travelling, such as the need for individual freedom, the need for taking certain limited risks, and the need for a certain (fixed) travel-time per day, including time to ‘disconnect’ work from home. An external factor that also causes uncertainty is how the legal system (liability) concerning AGV applications will develop, particularly where automated control and individual decision making interfere (for example, van der Heijden and van Wees, 2001). In studies where the system boundaries are taken narrowly, the future sprawl of living centres and work centres are often addressed as important external factors. A certain density of traffic flow appears to be a condition for the feasibility of particular systems of AGV. Despite such analysis, there remains a lack of understanding of future spatial patterns and their impacts. In a similar vein, the directions of technology development and cultural changes as independent influences are little known. Most of these external uncertainties can be attributed to the fact that the external environment is many-sided (different sectors and actors) and often turbulent (rapid changes), and therefore inherently difficult to predict.

Major uncertainty exists about system performance and responses, that is, the way the system will develop in reaction to the various inputs. There is significant uncertainty about the key mechanisms that determine system behaviour (structural uncertainty). This manifests itself, for example, in a lack of knowledge about gains in flow rate, density and time, although knowledge is now increasing about changes in mixed (semi-automated and manual) traffic (Bose and Ioannou, 2003). Little is known about the relationships among specific technological functions, such as cruise control in vehicles, routing information systems, tracing of goods and in-car communication about congestion. There is even lack of knowledge about individual acceptance and network operational network, but in Marsden et al. reliability and failure (in terms of partial and failure (for) of partial approach), failures affecting commands from types of drivers and standard class), with regard to the limited knowledge transport systems of infrastructure and location behaviour.

Knowledge is limited, in the novelty of the that implied a knowledge is separate piece situation following the passive role of opportunities in exchange of freight. As links with large single specific the AGV technical infrastructure? tasks? It is clear chicken-and-egg and developers: no clear insight. Note, however, of safety systems the market (Mi).

As a consequence, their particularly in often taken for help to reduce
about individual technological functions. For example, understanding user acceptance and the implications of adaptive cruise control is of great importance to network operators in charge of improving the capacity and safety of the road network, but the knowledge in this field so far is relatively poor (for example, Marsden et al., 2001). Further, an important point of uncertainty concerns the reliability and applicability of the technology in practice (for example, Bekiaris and Stevens, 2005). There may be a rapid increase in the vulnerability of AGV systems as a result of interference (for example, atmospherics, electromagnetics) and failure (for example, in sensor registration), particularly when a large number of partial applications are implemented simultaneously. Of course, fear of such failures affects market acceptance of systems in which drivers cannot overrule commands from automated control. A further point of uncertainty is how different types of drivers will appreciate different types of AGV applications. It seems that standard classifications using gender, age, education, and so on, are not adequate with regard to the propensity to accept the new applications. In addition, there is a limited knowledge about real-life influences on individual behaviour in the various transport subsystems, for example, persons’ and logistics firms’ driving, their use of infrastructure, their travelling behaviour, their activity patterns, and their location behaviour.

Knowledge about how AGV applications will affect the transport system is limited, in the first place, because it is almost uncharted territory: because of the novelty of the technology, no prior research was possible, except for experiments that implied a limited real-world validity. Another important cause of the limited knowledge is that new knowledge is gathered in a fragmented way, with many separate pieces that have not yet been connected in a systematic way. This situation follows from the nature of the market for AGV applications and the passive role of governments. Producers of new applications face good market opportunities in separate areas, such as drivers’ support in personal cars and tracing of freight. As a consequence, no attention is paid to compatibility and functional links with larger systems. In this context it should also be noted that there is no single specification of what an AGV system will look like (Marchau, 2000). Will the AGV technology be mainly connected with the vehicle or with the infrastructure? What will be the level of automation in terms of transfer of drivers’ tasks? It is clear that this lack of images of what AGV might look in practice is a chicken-and-egg problem: because of the prevailing uncertainties, decision makers and developers are hesitant to make clear choices and, as a result of that, there is no clear insight into probable system configurations, their impacts and acceptance. Note, however, that, most recently, knowledge is increasing about the specification of safety systems and road traffic efficiency systems that are almost ready to enter the market (Marchau and Walker, 2003).

As a consequence of the uncertainties in system surroundings and in system behaviour, there is a great deal of uncertainty about valuation of the policy outputs, particularly in terms of achieving the policy goals and how this is evaluated. It is often taken for granted that AGV serve to increase efficiency in infrastructure use, help to reduce emissions, and increase traffic safety. However, most information is
based on theoretical reasoning and small-scale experiments under strictly controlled conditions. Estimates about the impacts on the increase in road efficiency vary from as high as 100 per cent to as low as 20 per cent (Geels and Smit, 2000). The previous situation means a great uncertainty not only in reaching policy aims but also a great uncertainty about possible unintended or even adverse effects. The latter can be illustrated with the following examples. ICT-based efficiency gains in road freight transport may compensate for the increased price of gasoline, a policy measure taken in the context of advancing modal shift. Similarly, increasing efficiency in flow may lead to shorter travel times and lower consumer costs, which, however, may make mobility more attractive and ultimately cause longer commuting distances and an increase of energy use rather than a decrease. There is a clear uncertainty concerning the values (importance) given to various impacts likely to be produced by AGV. What is evident is that the generally accepted core value of individual freedom to make choices as a driver (traveller) is challenged by particular types of AGV, but the repercussions of this situation for the practical implementation of AGV are largely unknown.

As a result of all the above uncertainties it is not clear which new types of AGV are to be preferred, meaning that policy makers lack a sound basis for choosing measures with respect to AGV that will help reach their transport policy goals. Uncertainty about external influences beyond control and uncertainty about system performance and responses seem the most serious types of uncertainty contributing to this situation.

### 6.5 Coping with Uncertainties

Given the causes of the most important uncertainties identified in the previous section, traditional risk analysis type of approaches based on probabilities are not useful. Uncertainty about future developments in the external factors is partly unknowable, and may at best be partly specified. Most uncertainty about system responses is structural. From the possible strategies identified in Section 6.3, the ‘do nothing’ option seems to have been the most popular so far with most governments, not because of the conviction that the interplay of societal forces will automatically result in the best system, but because of lack of a vision in the face of the immense uncertainties. One of the results is a fragmentation of approaches and of knowledge build-up, which in turn does not help reduce uncertainties at a more comprehensive level. However, some of the other strategies seem to be more promising.

First, uncertainties in the external factors could at least partly be identified by developing a set of possible scenarios. Such a scenario-analysis may also help to increase policy makers’ alertness with respect to the relevance of external factors. Scenarios of the future also provide support in designing robust policies, that is, those that produce favourable outcomes under most of the different scenarios. However, a crucial need in scenario development for AGV is to include serious trend-breaks, but these are difficult to identify. Perhaps there will be a series of
serious collision accidents, maybe a merger between important manufacturers of equipment leading to scale economies and a fall in consumer prices? Secondly, several of the approaches to reduce uncertainty could be exploited, such as:

- Additional research and a better integration of existing knowledge about AGV implementation and its impacts. Additional research should depict the new applications in a real-life situation or its simulation, cover a sufficiently long time period to identify impacts in the different subsystems, and should reveal important links among different applications.

- Research on uncertain external factors, to gain, for instance, a clearer picture of legal issues (for example, product liability aspects of the systems) and how they may be resolved (van der Heijden and van Wees, 2001).

- Reduction of the number of possible system configurations and development paths by systematic feasibility analysis. This would lead to the elimination of technically improbable or impossible system configurations and reduce the set of possible ones to a more manageable size (Marchau et al., 2000). Exploratory modelling (Bankes, 1993; Walker et al., 2001) may also help in mapping out the possible development patterns.

- For each of the specific AGV applications, identifying uncertainties in adjacent policy fields like spatial planning and, where possible, improving coordination with policy makers in such fields.

- With regard to user acceptance and behavioural response in driving, increasing insights from social psychology, particularly in identifying relevant categories of users.

- Regarding the implementation of specific applications, granting the possibility of participation of relevant individuals and groups in policy making. For example, trucking company owners, drivers and highway police officers would be involved in selecting technologies for traffic monitoring and lane assignment. Such an approach fits current policy-making cultures in Western Europe.

A third strategy to deal with uncertainty is to develop smart policies in the presence of inevitable uncertainties. This would not mean investing in all feasible technologies and development paths. Rather, a flexible or adaptive policy is preferred, which is adaptable to the future course of events and can fully exploit the lessons of experiments and research that will become available as time proceeds (Marchau and Walker, 2003). This would imply combining policy actions that are time urgent and policy actions that preserve needed flexibility in view of future adaptations. A specific kind of adaptive policies is the one that has a focus on real options, meaning the design of a broad policy which leaves open various realistic options that can be used immediately if it becomes apparent that they are attractive. This may be true for specific provisions in new road infrastructure and for new safety measures concerning the technical conditions of cars, the latter anticipating a large-scale adoption of in-car sensor systems. The real-options
approach allows for the valuation of risky projects, while accounting for the contribution of active management or flexibility, as in terminating projects that are not working out and expanding those that perform well (Neely and de Neufville, 2001). The operationalization of the previous adaptive policies may be easier if specific visions are developed for specific AGV applications in specific subsystems of the transport system, provided that possible interactions among the subsystems are monitored in the implementation and adaptation process (van der Heijden and Marchau, 2002). A vision should also include normative choices; for example, with regard to the distribution of costs and benefits and the extent to which there should be interference in individuals’ driving behaviour in terms of freedom and responsibility.

6.6 Implications for Policy on ITS

Policy makers so far have adopted a mostly passive role, but there are many good reasons to become more active in view of the potential contributions of ITS to overall transport policy goals. In the light of uncertainty, any policy adopted should be a flexible and adaptive one. Important elements of developing and implementing such a policy include:

- Development of a vision of the policy goals to be achieved by the implementation of ITS, both at the level of individual applications and at the overall system level (including relevant core values).
- Development of scenarios to identify key uncertain factors in the system’s surroundings as a basis for coordination with adjacent policy fields and for the specification of factors to be monitored as time proceeds.
- Analysis of possible ITS configurations and development paths, the results of which will also help to identify critical assumptions and thus contribute to the specification of factors to be monitored.
- Research into the impacts of both isolated ITS applications and integrated ITS systems, with a particular emphasis on building up integrated knowledge and on indirect effects, taking into account the full complexity of the transport system and its interrelated subsystems.
- Research on specific topics such as liability issues and factors influencing user acceptance and user perceptions of failure of the technical systems.
- Selection of small-scale experiments in real-life settings that allow for learning, and in which the major stakeholders are involved.
- Development of an understanding of vulnerabilities of the policy and the design of monitoring of key manifestations of these vulnerabilities.
- Development of guidelines for policy adaptation or other corrective actions, that is, indications of what steps to take next, given specific experimentation outcomes, research findings and monitoring results.

In this section, we have considered how the traditional risk analysis procedure can be modified and subsequently integrated with the shifting knowledge about the impacts of ITS.

6.7 Conclusions

We believe that the development of the typology proposed in this paper and the analysis of its uncertainties can be very useful for further work in the field. The typology promotes a more explicit focus on uncertainty, which is an important element of any policy. It also provides a basis for a more systematic and systematic approach to the development of ITS policy by identifying the key uncertainties that are likely to be encountered and by providing a framework for addressing them.

In this chapter, we have identified and described the possible way in which the typology can be used to address the uncertainties that are likely to be encountered in the development of ITS policy. The typology is based on a combination of the general principles of uncertainty analysis and the specific needs of ITS policy. The typology provides a framework for addressing the uncertainties that are likely to be encountered in the development of ITS policy.

In particular, the typology provides a useful perspective on the different types of uncertainty that are likely to be encountered in the development of ITS policy. The typology can be used to identify the types of uncertainty that are most likely to be encountered in the development of ITS policy and to develop strategies for addressing them. The typology can also be used to develop strategies for addressing the types of uncertainty that are most likely to be encountered in the development of ITS policy.
6.7 Concluding Remarks

We believe that the approach and typology of uncertainty set out here will be helpful to both practitioners and researchers in policy analysis for identifying uncertainties and dealing with them in the context of transport technology. The typology provides a broad diagnostic tool for examining the nature and causes of uncertainty, using a basic systems input-output model. Four important classes of uncertainty can be summarized according to their relation with the system: 1) system boundaries; 2) external inputs to the system; 3) performance and response of the system to external factors – all three leading to uncertainty about the relevant system outcomes; and 4) valuation of the policy outputs. As a result, choosing the right policy option to reach policy goals often lacks a sound basis.

In this chapter, we have demonstrated how the typology of uncertainties and of possible ways to deal with them can provide guidance to identify the key relevant uncertainties, their sources, and the most appropriate policy strategies in view of those uncertainties and stakeholders’ preferences. We do not claim that our typology is better than the others, but we argue that a typology in the context of policy analysis needs to be clear and systematic in terms of causal structure of the uncertainties, and needs to provide a solid ground for generating strategies to deal with these uncertainties. The framework also seems sufficiently generic to be applicable to many other policy issues than new transport technology, on the condition that a systems approach is used. The AGV example illustrates a more general phenomenon: namely, that the key uncertainties involved in many strategic policy issues are structural, and cannot be dealt with using classical, mostly quantitative methods, such as those developed in risk analysis. Rather, a combination of further knowledge acquisition using more qualitative approaches and learning with flexible, adaptive policies, is often needed.

In particular, we would like to address future research on uncertainty from the perspective of the stakeholders. The framework developed in this chapter uses the perspective of the policy maker. An equally important perspective in arriving at the best policy results is that of the major stakeholders in the field. There is an increased dynamics in stakeholder importance and in shifts in their positions. Thus, it is highly relevant to know how different stakeholders deal with uncertainty, for example their perceptions of system boundaries and problem perceptions, interpretations of model outcomes and valuations of (potential) policy results.
Notes

1 As uncertainty in making the right policy decisions follows from all other classes of uncertainty, this type of uncertainty is not regarded as a separate class.

2 With regard to the identification and assessment of uncertainty in the practice of implementation, we refer to Bekiaris and Stevens (2005).

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An integrated transport policy and planning

7.1 Introduction

Substitution between transport modes is desirable for the achievement of environmental targets. For example, in the US, a shift from traditional airlines routes to air travel provided by rapid rail (Caves and Richardson, 1990) would have a number of benefits: reduced emissions, improved access for passengers, reduced costs, and increased capacity. One to investigate is the impact of a new high-speed rail network, the HST network.

For the purposes of this case study, the content will be focused on the scenario where the HST network is introduced. The introduction of the HST network will lead to a substitution of the conventional air travel market with the HST network. The impact of this substitution will be analyzed in terms of its environmental, economic, and social benefits.

Under these conditions, it is expected that the company