IMPACT OF DISRUPTIVE INNOVATIONS ON ROAD TRANSPORT STRATEGY

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Abstract
Scenario describing the future include many disruptive innovations, which implies that traditional models calibrated on historical data are not always applicable for quantification of these scenarios. This paper describes disruptive changes to be expected which will influence the reliability of forecasting approaches used for road transport assessments and which changes to these approaches can be recommended. Also adaptions to the forecasting framework are proposed and the key modelling issues to be improved are indicated. Some aspects will remain hard to predict and in these cases additional pro-active mitigation actions are recommended, such as flexibilization of the infrastructure and location policy for economic activities.

Keywords: Vision, Innovations, Logistics, Multi-Modal, Road, Transport.

1. Introduction

In many scenarios on future development it is expected that in the coming decades disruptions of the societal system/economy due to innovation will occur more frequently than we have observed up to now; the future will be significantly different than what we have observed in the past. The existing forecasting model paradigm being applied in making the quantifications of these scenarios, is originating largely from the 70'ies when developments were gradual, potential for improvement of economic welfare was large and restrictions for required resources were not relevant within the forecasting horizon. In this context it was relatively safe to assume that the developments present in historical data could be used for forecasting possible future scenarios. Given the foreseen disruptions innovations, which by definition imply changes to the patterns observed in the past, it should be concluded that the existing forecasting/modelling paradigm is no longer valid and a new methodology has to be developed. This new methodology should still make use of the historical data where appropriate, but should include alternative methodologies where this is not the case.

> The National Research Council (NRC) of the USA has stated (2010): 'All forecasting methodologies depend to some degree on the inspection of historical data. However, exclusive reliance on historical data inevitably leads to an overemphasis on evolutionary innovation and leaves the user vulnerable to surprise from rapid or nonlinear developments. …. A methodology that can forecast disruptive technologies must overcome the evolutionary bias and be capable of identifying *unprecedented change*.' Further the NRC concludes: '… no single method of technology forecasting is fully adequate for addressing the range of issues, challenges, and needs that decision makers face today. … a combination of methods used in a persistent and open forecasting system will improve the accuracy and usefulness of forecasts.'

This paper describes disruptive changes to be expected which will influence the reliability of forecasting approaches used for road transport assessments and which changes to these approaches can be recommended. First an orientation is done on fundamental changes that can be expected and the direct implications of disruptive innovations. Also some key disruptive innovations within the transport sector are discussed as well as other innovations that will influence the predictability of traffic flows. Finally adaptions to the forecasting framework are proposed as well as the key modelling issues to be improved.

2. Fundamental changes

2.1 Disruptive innovations

In literature, disruptive innovations are defined in different ways depending on the application purpose. For the purpose of forecasting for strategic assessments we have defined disruptive innovations as follows (DISMOD, 2017):

- A disruptive innovation is an innovation (or technology) that affects firms in the way they produce products or services, and / or it affects consumers in the way they use products or services that build on the innovation (or technology). The latter includes the use of a novel product or service. An innovation is said to be disruptive if, and only if, the market will

change such that it will ultimately be dominated by those actors that have adopted this innovation.

- Innovations can also be disruptive in non-markets; in case of public goods. An innovation is subsequently defined as disruptive if delivery and / or use of the good or service is dominated by the respective innovation.
- We maintain that there is no level of disruptiveness: an innovation (or technology) is disruptive, or it is not disruptive (i.e. disruptiveness refers to a binary status). This status is not an outcome at one fixed point in time, but based on the evolution of the impact of the product or service over time.

Note that the definition does not differentiate between demand driven and policy driven disruptive innovations. Examples of policy driven disruptive innovation concerns for instance the energy transition, which is addressing the need for climate change mitigation and future scarcity of non-replaceable energy resources. Policy driven disruptive innovations can evolve into a market driven disruptive innovation.

2.2 Speed of innovation

Production and testing
A development observed in ICT industry is that applications are sent to market as soon as possible. Applications are combined with a back-end application which collects the feedback from users, based on which improvements to the application are made. By frequent software updates the improvements are sent to all users in a very short time. In this way not only errors can be removed, but also different options/functionalities can be tested and compared. Thus users have become part of the development process which saves development costs and is done more thoroughly since the test panel is very large. (O'Reilly, 2017)

Innovations requiring physical investments the situation is different, since the product has to be tested and completed before full scale implementation can be done. In case of robotics this concerns especially the physical aspects since also here software updates can be done after implementation (for instance Tesla cars).

Market uptake
As can be derived from this definition, disruptive innovations imply a transition process. In case of software based innovations (such as Uber of Airbnb), uptake does not require much effort in terms of physical adaptations. As such, uptake by majority of the market can be achieved within months. In cases where physical adaptations are required the process takes longer and investments are higher than for software applications. However automation of production and facilitating processes gradually reduce these costs and increase the speed of implementation.

Convergence of innovation
Technologies that have been in development for a long time, are now maturing. When combined with other matured technologies this will lead to a sudden acceleration of innovations, which is called technology convergence. This implies that although innovation already seems to be at full speed, we should be prepared for a further acceleration (exponential growth of innovation) (Brynjolfsson & McAfee, 2014).

Financial sector judgments

The financial sector plays an important role in the economic system. Strategic decisions made by this sector therefore can have major impacts on the rest of the economy. An innovation disrupting (or replacing) a complete sector will have large consequences for the companies active in this sector. Especially when such innovation would not be anticipated this will lead to many bankruptcies in a short period of time. This will imply that many loans cannot be recovered by the banks. Since this then involves many companies for a sector, and in the worst case even for several sectors at the same time, the accumulated loss taking could be significant. In which degree this scenario would affect other parts of the economy will depend on the absorption potential of the banks in consideration. Given the potentially large impact of such an unanticipated event, it seems likely that the financial sector will anticipate to potential disruptive innovations wherever possible. In that case this will lead to appropriate measures, which could for instance imply higher interest rates, shorter pay-back periods and other additional conditions that will make it harder for the incumbents of a sector to get a loan. This will reduce the risks for the financial sector and will at the same time lead to a more pronounced/accelerated disruption due to the reduced potential to invest/compete by the incumbents. (DISMOD, 2017)

2.3 General implications of disruptive innovations

Demand saturation & limits to labour demand

Technological progress could increase production efficiency in all sectors. Historically we have seen similar developments leading to a boost in the GDP (Graetz & Michaels, 2015). Where traditionally the robots compete in particular with the low-skilled jobs, now the occupations at risk are more diverse, putting also the middle- and higher-skilled jobs at risk. A study by Frey and Osborne forecast that by 2030 about 47% of all jobs in the US could be automated (2013). The broadness of such a system change and especially the speed with which the disruptions are following each other up, is unprecedented and therefore the impact of it is not straightforwardly determined by use of historical indicators.

The relationship between the quantity of consumption of a particular good or service and the household income is represented by the Engel curve. The Engel curve for a particular good or service indicates its income elasticity and classifies the goods into inferior, normal or luxury. Demographic and other consumer characteristics influence the shapes of Engel curves. For the majority of goods, the income elasticity declines with income, meaning that the share of budget spent of a particular good declines as consumers become richer. At the same time, some Engel curves display even a stronger boundary condition; an absolute consumption ceiling which shows an absolute limit of expenditure on this good. The underlying reasons for convex or sigmoid Engel curves are, *inter alia*, the bounds of wants for a specific product, constrained replacement rates of the durables, emotional attachment to durables, the limits of time budget devoted to consumption. (Moneta & Chai., 2014)

Process innovation increases efficiency per unit of product and simultaneously it increases demand. The production/labour level is the same as before the innovation only if the increase in demand is equal to the increase in efficiency. However historically it is merely observed that

product innovation leads to increase in product demand and to a reduction in labour demand (for production of this product).

Combining this with the analyses of the demand saturation, we will see that in case of radical productivity improvement the total output will asymptotically approach the saturation level. At the same time, the growth of the productivity of this sector will lead to a decline in employment if the productivity growth goes faster than the growth in demand. As such, additional labour is historically created by production of additional products and creation of additional markets. (Aoki & Yoshikawa, 2002)

Globalisation has provided an opportunity for further growth in developed countries and has stimulated consumption in developing countries. However, expenditures can only be further increased when salary increases, but in this closed system (global economy) there is no alternative market where additional income can be generated by exports. (DISMOD, 2017)

Inequality
In practice, the global economy is not homogenous and therefore we will experience the interaction of two sub-systems: rich countries and developing countries. It seems likely that automation will be better possible for those having much capital. Consequently, cheap automated production could be increasing faster in richer countries creating saturation. (DISMOD, 2017) To limit unemployment in these countries, excess production will be created, which in this case should be exported to developing countries as long as demand could still increase. The Centre For Global Socio-economic Change (CFGSEC) has shown that that an increase of inequality between countries is eventually in balance with a lower GDP level (2016).

Resource and Energy transition/disruptions in a global perspective
A clear interdependency between important variables that are shaping our future, is often overlooked. Here below a (decomposition) formula is shows that represents the total global (so a closed system) demand for resources as a function of population size, the global average GDP per head (welfare) and the resources required to generate one unit of GDP (resource efficiency).

$$resourceDemand = population \times \frac{GDP}{person} \times \frac{resources}{unitGDP}$$

In case of scarcity of a resource aiming for global GDP growth will require an increase of the resource efficiency. Failing to do so, would lead to a slowdown or decline in global GDP growth, increased inequality between and within countries and heightened risk of global political instability. For reduction of use of carbon-based energy resources this function also applies and implies a nearly complete transition to sustainable energy sources in case we want to avoid a reduction of GDP growth. (Chen et al, 2016).

3. Disruptive innovations transforming the transport sector

3.1 Networked environment in the transport sector

Technological innovation is opening up many opportunities with an accelerating pace for many sectors including the transport sector (Chen T.M., Bodea B., Huijboom, N., 2016). Artificial

Intelligence (AI) can take over many tasks involving not only simple repetitive tasks but in the not so far future this will also be the case for increasingly complex tasks (Brynjolfsson E., McAfee A., 2014). AI eventually will have the potential to outperform humans on aspects of importance within the transport system, amongst others on reaction time, optimisation and organisation (Frey, C.B. & Osborne, M.A., 2013). In order to make optimal use of this potential, much attention is spent on automation of vehicles and organisation (Physical Internet) and at the same time also new modes (Hyperloop, pods) and services (Mobility as a Service (passengers)) arise. Many innovations become possible due to the increasing possibilities for entities/objects to interact with each other and as such collectively create a networked environment. In this networked environment optimisation and decision processes will be installed that can anticipate to emerging situations in the network and can also react real time to unforeseen changes.

3.2 Logistics development

A point at the horizon for logistics and transport has been developed within SETRIS projects by cooperation of the relevant ETPs including amongst others ETP logistics (ALICE). This has resulted in a roadmap with amongst others the following aspects:
- hub oriented organisation where shipments are brought to the nearest hub and from there is transported in a system optimised way to the hub closest to the destination.
- Transhipments at (intermediate hubs) are done automatically without human intervention.
- Distance between hubs should be chosen by optimising the balance between transhipment costs and optimal use of capacity of the vehicles.
- For long distance shipments more than one intermediate hub will be used.

3.3 Road vehicle automation

Within the road sector much attention goes to automation of vehicles and truck platooning. Platooning has an energy efficiency (and therefor also costs) reduction advantage due to improved aerodynamics and is also possible with level 3 automation of trucks.

Level 4 automation will imply that on designated roads no driver is needed. For trucking this could open up new (labour) cost reducing logistical organisation options. For instance drivers could bring and pick up trucks to and from the highway where the truck drives a long stretch by itself but even easier is to have hubs and distribution centres situated directly along the roads where unmanned trucking is allowed.

Level 5 automation opens doors to driverless road transportation which will be about 50% cheaper than the current alternative. By many this is perceived as a long term perspective not likely to be possible within the coming 10 years. However, given the general rapid and accelerating developments in ICT (for instance the use of self-learning systems), it cannot be ruled out that level 5 automation can be achieved within the coming 5 years. Tesla claims to be ready for level 5 automation around 2020 and will also apply this for trucks. Also other manufacturers have communicated similar time horizons for level 5 automation. A recent publication on diffusion of automated vehicles by TU Delft concludes that in 2025 the share of level 5 vehicles can be even upto 35% in the Netherlands depending on the policy instruments applied (Nieuwenhuijsen et all. 2017).

3.4 Balancing modal speed of innovation

Reduction of road transport costs by 50% makes road transport in some cases even competitive with bulk flows which currently are moved by rail. The rail sector does have R&I roadmaps, which are targeting a cost reduction of 50% as well. However besides this point on the horizon of the roadmap also the speed of development and market uptake are very relevant, especially given the short time frame that might still be remaining (see section 3.3). The Smart-Rail project (2018) has identified different barriers to overcome to bring back the balance in speed of innovation. The market for rail assets is smaller than the market for automotive sector, which implies that the R&I budgets are smaller. Also the life time of rail assets can be even 5 times longer than for trucks which makes the process of a transition by replacement at end of economic life time a too slow option. The rail system itself creates a barrier for changes by individual stakeholders; a major system change is needed to create more flexibility and allow for automation of the processes. So much will be needed to create a new balance between road and rail developments.

Although these signs might sound favourable for the road sector, it should be noted that a radical modal shift from rail to road will lead to more congestion rather than the reduction of congestion targeted by the investments in automated driving. In order to avoid resulting societal costs rail innovation should be brought in balance. Cross-fertilisation with the road sector developments might be a good option given similarities in innovation topics. This would also lead to additional benefits/changes such as harmonisation of vehicle communication, harmonisation of corresponding legislation, economies of scale due to larger market for innovations, etc..

3.5 Transport and Traffic flows

Production and supply chain innovations
Besides the development in the Transport and logistics sector itself also other developments will have an impact on the road sector. For instance robotics and AI are being integrated into concepts such as Mega Factories and 3D printing which will lead to radical changes in mobility and logistics patterns. The gravity between labour market (cities) and locations will diminish when fully automated Mega factories will appear. This implies that factories could in principle also be built in areas with low population density. Even automated ports could be built dedicated to the maritime connection of a Mega factory. A consequence for transportation on the inland side is that large flows of final products will be transported to inland DC for which inland modes will be used. In case the factory is not situated at the water then also land modes will be needed to deliver the bulk cargo as input for the factory.

Typical for current 3D printing is that products can be printed to the specifications of the client and therefore each output could be a unique product. Current insights are that 3D printing will focus the coming years on creating shapes that can't be produced efficiently with conventional production methods. However the capabilities of 3D printing will improve and costs of production will go down with the corresponding upscaling of the market. In the future simple 3D printing can be even done at home but the more complex product will be printed in dedicated locations. These could be small or large but will be situated near the market and therefor close to or in cities. The input to the process will be bulk commodities which could be largely transported by rail or inland waterways to distribution centres. From there it will be transported

to the 3D factories in smaller shipments. The output will be sent by a logistical service provider directly to the client or to pick-up places near the client or near the factory.

Disappearing and upcoming activities
Disruptions due to innovations will take place in a broad spectrum of sectors. This means that sectors are taken over by an innovation of another sector or of a completely new start-up; consequently in some areas freight flows might disappear and in other areas suddenly freight demand will arise. Since disruptions can happen in a very short time and are hard to predict, it is increasingly difficult to predict these changes to freight demand.

4. Improved forecasting framework

4.1 General vision

The overall methodology required to improve the assessment of scenarios with disruptive innovations is advised to be a persistent and open forecasting system (NRC, 2010). This includes amongst others the following characteristics:
- Persistent:
  - Acknowledge the uncertainty.
  - Monitor correctness of forecasts and identify deviations.
  - Continuously adapt and learn; improvement of methods ('policy model lab')
- Open
  - Expect to make new "wrong" forecasts.
  - Share new insights and methods.
  - Share knowledge (cross-sectoral, cross-project, …).

The DISMOD project has proposed and explored some key elements. In Figure 1 a generalised sketch is made of this forecasting framework. Beside the core elements currently in place also new elements are added in the second layer.
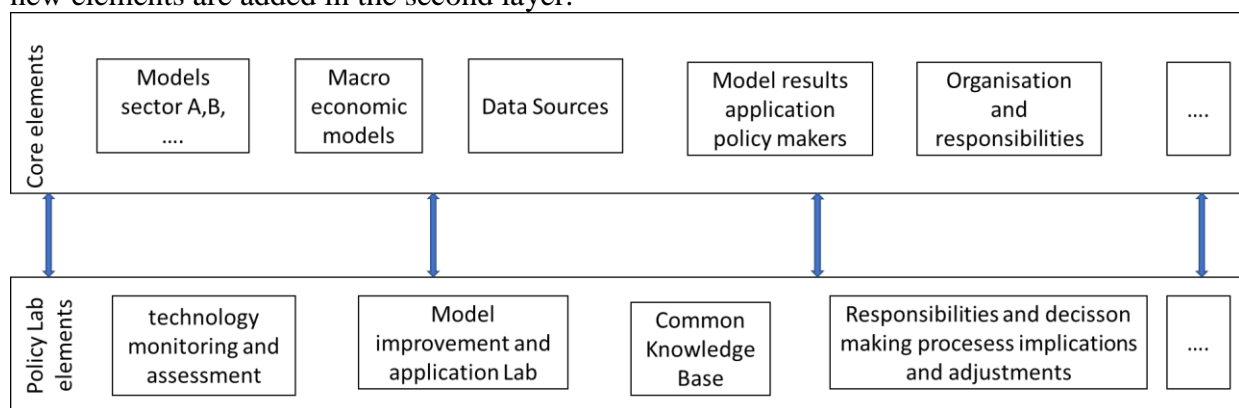

Figure 1 Vision forecasting framework

In many cases traditional modelling has to be complemented with other types of information and methods to fill the gaps. Here use can be made of softer information from stakeholder panels/workshops or by new approaches such as superforecasting (Tetlock & Gardner, 2015) in a networked environment. Since the risk arises that the methods applied and resulting outcomes will be depending on the person who performs the task, alternative 'standards' should

be set in place that can objectify the approach and information used. Information gathered should be shared so it can also be reused by other assessments. Technology monitoring and assessments of specific innovations should provide standard outputs such that the collective information results in a new data source that can be used in forecasting methods.

Since the current decision making processes often rely on the traditional forecasting models based on historical data, this can imply that the processes should be adapted as well. By use of a common knowledge base and shared information that keeps track of the information available at each moment in time, decisions can still remain defendable also if new information might lead to an opposite conclusion.

Much can be said about the new components to be added to the forecasting methodology and specific required improvements to models. The discussion in this paper will focus on some fundamental modelling issues and required improvements are highlighted in the next sections.

4.2 Weakening theory of a generally accepted scientific approach

Models are fit on historical data according to strict scientific standards. As such quantifying a long term scenario of the future by use of these models is by many automatically assumed to be a scientifically sound approach as well. However, this is not always the case.

There are two important criteria for which a model should fulfil:
- A good fit on the historical observations
- A theory supporting the design of the model and the (implicit) assumptions made

These two criteria are often interlinked when the theory is focussed and adapted to the observed patterns. There are scientific methods designed to determine the predictive power of a model. However this can of course only be applied by use of historical data. A popular approach is to perform a back-casting to the past starting from the base year and compare the results with past observations with one of the goodness-of-fit measures. This approach is often claimed to provide scientific prove that a model has a high predictive power, even though it is only based on historical material.

The predictive power is of course also very much depending on the underlying theory that supports the design of the model. This is something very important that can be easily forgotten when using the model for future scenarios. As long as the scenarios do not include drastically system changes this approach is defendable and has therefor become a successful approach which was gained popularity since the 60íes- 70-ies when these approaches were invented. As such this approach has become imbedded in the now broadly used approaches for assessment of long term investment, impact assessment methodologies and policy making processes. This has provided the additional 'quality' label to the methodology as being a 'generally accepted approach'. Consequently the question whether the underlying theory is still valid for the future is not very often questioned anymore.

There is a large variety in scenarios currently being assessed that can include many disruptive innovations like the ones described in the earlier sections of this paper. As such it should be

recognised that the assumption, that patterns observed in the historical data will also apply for the future, is in many cases not valid anymore.

4.3 Model theory and function type selection

The selection of the function type to be applied is by many determined as when determining the best fit on historical data. However, especially when applying the model for forecasting the function type should be regarded as part of the underlying theory. Especially when changes are large the function shape is very influential.

As an example we can look at productivity improvements which traditionally were in the range of a few percentage points and consequently the demand and labour impacts where of the same order. This implies that when we zoom out, all changes occur in the bottom left corner of the quadrant, which might very well be represented by a linear or some other function types as well, without creating significant deviations. Now we are experiencing radical productivity improvements already with examples of fully automated factories creating a productivity improvement of several thousand percentage points. When these technologies will be broadly applied this will create impacts of similar size at sectors level. This will imply that saturation levels become relevant and function types have to be adjusted accordingly.

Market penetration of (successful) innovations should be represented by an S-curve (logistic function) which also includes a saturation which can often cannot be observed yet in historical data. In some cases an exponential curve might provide a good fit but this function type should only be used when the underlying theory supports the unlimited potential for growth that it represents. The full product cycle would also include the replacement of an technology by a new innovation. In this case for instance a normal-curve could be a better fit. For operational technologies being replaced by a new technology an inverse S-curve will have the best fit (second halve of the normal-curve).

In case the historical data do not support the theoretically correct function type this can imply that not all required variables are taken up in the model. For instance an S-curve might not fit on the entire market because the market penetration consists of a sequence of different type of consumers with different preferences. Early adapters often look for status but could also include a segment that anticipates very fast to financial benefits such as is also the case with subsidies. For the same product the majority might just want the straightforward costs reduction. The S-curve therefor is not always smooth and should sometimes be split in market segments.

A possible mismatch can also occur because (implicit) assumptions are incorrect. For instance the Dismod project has assessed the modelling of the solar panel market which in the past decade has been forecasted incorrectly by nearly everyone (2010); prices were predicted too high and market uptake too low. In this case besides the use of the wrong function type also the assumption that the principles of a market economy could be applied seemed to be, at least partially, incorrect. The fact that uptake of solar energy was becoming part of a global agreement was not part of the model and its inputs. The influence of the policy of China on the outcomes is very large and as such the demand for solar panels is policy driven rather than demand driven. Consequently global prices of solar panels went radically down and demand

went up. So in this case the assumption that the market economy principles apply, turned out to be incorrect.

4.4 Quantifying disruptive scenario changes to variable and parameter values

Not all functions and models will be affected by disruptive changes. To be able to judge whether a function is still applicable it is most convenient to work with models which have a clear link with the empirical data. (For instance dynamic models do not qualify.) This link with the historical data can be used for the definition of a fit-for-purpose norm for functions and models.

A proposed rule that could be applied is that input variables and model parameters within a confidence interval of 95% (2x standard deviation) can be applied without problems. In case they fall in a range upto 4x standard deviation it becomes increasingly unlikely that the model can cope in a reliable way with these shocks. In these cases a thorough assessment has to be done on the underlying theory and assumptions before a conclusion can be made. Where the values change more than 4x the standard deviation it can immediately be assumed that this function is not applicable and other methods should be looked for. (Dismod, 2017)

4.5 Innovations disrupting forecasting approaches

Last but not least it should be noted that new technologies such as deep learning and use of Big Data can make it possible to develop more sophisticated models. Where in aggregate data cause and effect might remain unclear, this could become visible in large detailed data sets. Large time series can make it possible to identify functions for elasticities. New meaningful constants, correlations and theories can be discovered by deep learning would not be possible by human observations.

5. Conclusion and discussion

This paper provides insight in general an transport sector specific disruptive developments are described. Although some aspects should be assessed more thoroughly, some general conclusions that can be drawn:

- The speed of change is higher than in the past
- Radical productivity improvement will have major distribution effects for GDP growth and the labour market (so also for freight demand and traffic).
- There will be a tendency towards growing inequality between countries, favouring the developed countries and risking a lower global average welfare level.
- New transport concepts and automation will lead to more efficiency and cost reduction and changing traffic patterns.
- The balance of speed of innovation between road and rail should be ensured in order to avoid a shift from rail to road leading to road congestion and corresponding societal costs
- Traffic flows will become harder (or impossible) to predict due to disappearing and upcoming activities and corresponding freight flows, due to disruptive innovations in different sectors.

From these results it is clear that we need to adjust the forecasting methodologies for forecasting and assessment of policy impact. New ways of collecting information and sharing knowledge

should be developed and policy making processes should be adapted accordingly. Selection of function type should be explicitly be part of the theory underlying the model rather than the model calibration. New technological possibilities such as deep learning in big data should be applied in model development.

Some issues require additional pro-active mitigation actions in order to optimise the impacts of innovations currently being made. A possible pro-active strategy to deal with uncertainty of traffic flows is to aim for flexibilization of the infrastructure. Also strategies can be developed to influence the choice of location for new or shifting economic activities such that the (freight) transport demand becomes more predictable or at least the number of possible outcomes will be reduced.

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